Appendix A

Previous Hydrogeological Investigations

HYDROGEOLOGIC SITE CHARACTERIZATION

FOR
OTTAWA COUNTY FARMS LANDFILL
LAIDLAW WASTE SYSTEMS, INC.
15550 68th AVENUE
COOPERSVILLE, MICHIGAN 49404

AUGUST 1995

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DBV/ck:BAL/LRD

EXECUTIVE SUMMARY

A hydrogeologic investigation of the Ottawa County Farms Landfill, Ottawa County, Michigan was performed by Dell Engineering, Inc. (Dell) on behalf of Laidlaw Waste Systems, Inc. (Laidlaw) to meet the requirements of Part 115 of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, as amended (formally Act 641, the Michigan Solid Waste Management Act, PA 641 of 1978). All "Rules" referenced in this document correspond to former Act 641 and the rules promulgated thereunder. A detailed hydrogeologic site investigation is required by Part 115 to (1) characterize the areal and vertical extent of earth materials, (2) determine the hydraulic properties of soil and bedrock units, (3) define the uppermost aquifer and aquifers hydraulically interconnected to it, (4) determine the groundwater flow direction, flow rates, and vertical and horizontal gradients of the aquifers, and (5) determine the groundwater quality and background quality in the aquifers.

An overview of the regional geology and hydrogeology was performed to establish a benchmark for comparison to site conditions. The site is located on the western side of the Michigan basin. The basin is filled with approximately 2,400 feet of consolidated sedimentary rocks and is mantled by as much as 400 feet of unconsolidated glacial sediments. The basin-fill sedimentary rocks are primarily shale, sandstone, and limestone and the glacial sediments are clay, silt, sand, and gravel deposits. The principal aquifers in the basin are contained within sandstone bedrock, and sand and gravel deposits. Groundwater in the western part of the basin generally flows from east to west, consistent with basin topography. The Marshall sandstone contains the primary water-producing zone in the region and the glacial sediments produce substantial amounts of groundwater locally. These soil and bedrock units are the focus of this investigation because they underlie the site.

An evaluation of the site geology is required by Part 115 to characterize the areal and vertical extent of earth materials at the site. The evaluation is required because earth materials control site hydrogeologic and aquifer conditions. The geologic investigation focused on determining the depth to bedrock and the stratigraphy of the overlying glacial sediments. Twenty borings, five of which penetrated bedrock, were drilled at the site to determine the glacial sediment and bedrock stratigraphy. Bedrock beneath the site consists of limestone and sandstone of the Marshall Formation and is overlain by approximately 200 feet of glacial sediments. The sediments are divided into four stratigraphic units based on their hydrogeologic characteristics; from top to bottom, they include (1) an upper clay unit which is 90 to 150 feet thick, (2) an upper sand unit which is 5 to 55 feet thick, (3) a lower discontinuous clay unit which has a maximum thickness of approximately 60 feet, and (4) a lower discontinuous sand unit which has a maximum thickness of approximately 25 feet.

An evaluation of the site hydrogeology is required by Rule 904 to define the uppermost aquifer beneath the site and determine the flow paths and hydraulic characteristics of the aquifer(s). During soil boring operations, Dell installed eight monitoring wells and four piezometers to determine groundwater flow direction, flow rates, and horizontal and vertical gradients beneath the site. Four monitoring wells were in place prior to this investigation. For the purpose of this investigation, the piezometer/monitoring well network includes six shallow monitoring wells (DB-5, DB-15, MW-11, MW-12, MW-1R, and MW-2R), six intermediate monitoring wells (DB-11 and DB-16 through DB-20) and one intermediate piezometer (DB-14), and three deep piezometers (DB-1, DB-2, and DB-3). A conceptual hydrogeologic model was developed based on data collected from this expanded network. The conceptual model is the foundation on which the site's Environmental Monitoring Plan was developed.

Fractured limestone and sandstone of the Marshall Formation have moderate permeability and contain a regional aquifer which is an estimated 200 to 300 feet thick. This bedrock aquifer underlies the entire site and is the primary source of drinking water in the area. Sand units in the overlying glacial sediments contain the uppermost aquifer at the site. The sand units have moderate permeability and are hydraulically interconnected with each other and the lower bedrock aquifer. Groundwater in the lower aquifer flows northwest and groundwater in the uppermost aquifer flows southwest. Groundwater flow in the lower aquifer is probably influenced by extensive groundwater pumping from farm and commercial water wells completed within this aquifer west of the site. The site is in an aquifer recharge area characterized by downward hydraulic gradients. Groundwater in the lower and upper aquifers moves under a similar hydraulic gradient which ranges from 0.0014 to 0.0025 foot per foot (ft/ft). The average groundwater flow velocity in the lower aquifer is 39.5 feet per year (ft/yr) and the average flow velocity in the uppermost aquifer is 9.9 ft/yr.

Dell conducted a groundwater sampling and analysis program at the site to meet the requirements of Rule 904. Results of this program indicate that groundwater in the upper and lower aquifers has not been impacted by landfill activities. Additional groundwater chemistry data from future sampling events, combined with data from this report, is intended to establish background groundwater quality for the aquifers.

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1.0 INTRODUCTION

Dell Engineering, Inc. (Dell) presents in this report a hydrogeologic characterization of the Ottawa County Farms Landfill, Ottawa County, Michigan. The investigation was performed on behalf of Laidlaw Waste Systems, Inc. to meet the requirements of Part 115.

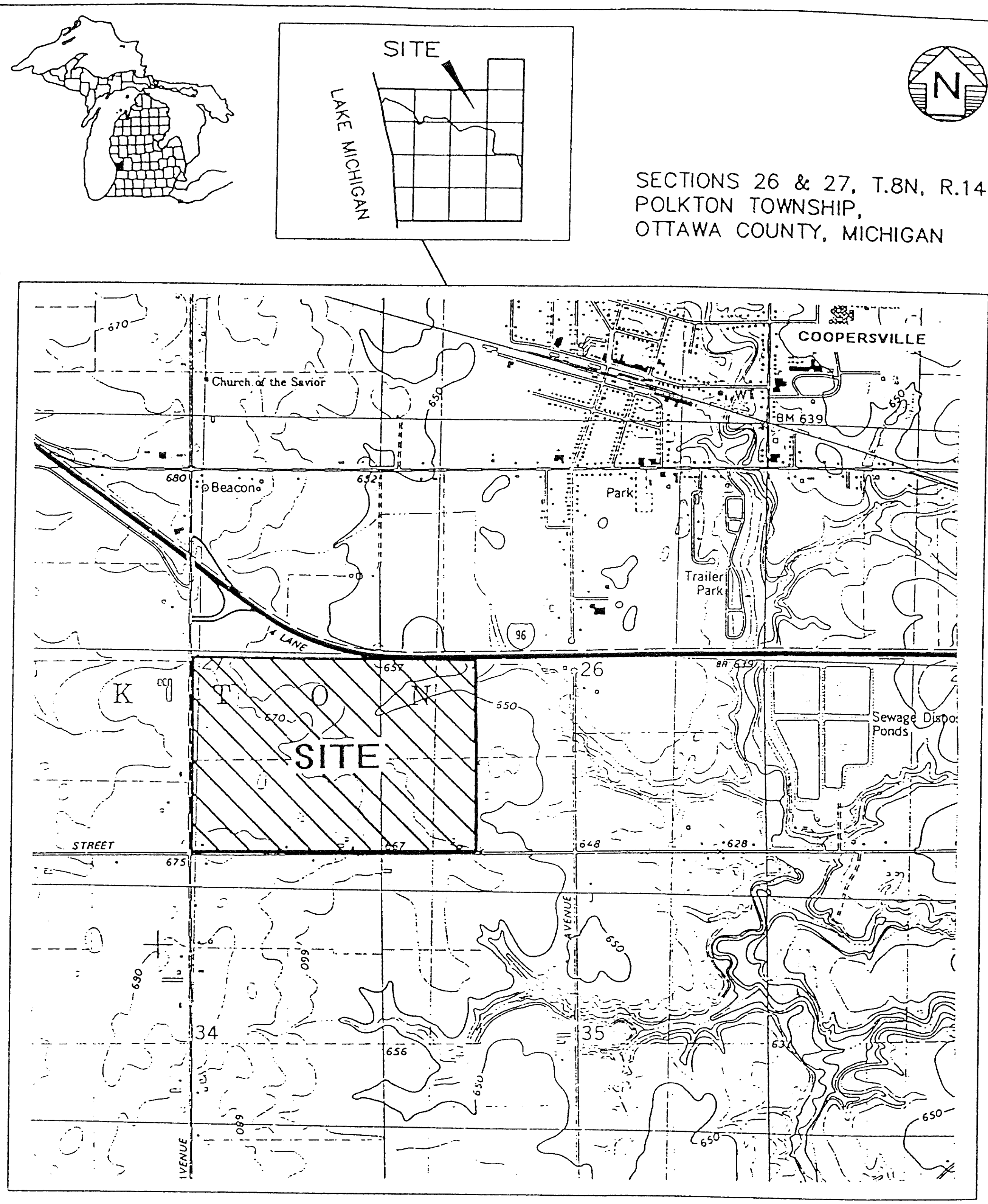
1.1 Site Description

The Ottawa County Farms Landfill is a 240-acre Type II solid waste disposal facility located approximately 0.5 mile south of the City of Coopersville in Sections 26 and 27 of Polkton Township, Ottawa County, Michigan (Figure 1). A legal description of the site is provided on Sheet 1 of the *Engineering Report* (Dell, 1995a). The topography of the area is formed by glacial features with the highest elevations associated with recessional moraines and the lower elevations with the Deer Creek drainage system. Elevations range from approximately 680 feet above mean sea level (USGS) along the southwestern part of the site to approximately 600 feet USGS along Deer Creek, east of the site. Surface drainage is generally from west to east into Deer Creek (Figure 2). Land use in the area is primarily agricultural with some industrial uses north of the site in the City of Coopersville.

Sites defined under the Michigan Environmental Response Act, Public Act 307, as amended (MERA) and sites containing leaking underground storage tanks (LUST) have not been identified within 0.5 mile of the site (Michigan Department of Natural Resources, 1993).

1.2 Site History

Disposal operations at the site began in 1982 and have included the licensing and construction of five sequential cells (Cells A through E). The landfill accepts residential, commercial, and non-hazardous industrial waste. Waste has been placed on most of the constructed area with the northern and northwestern portions near design grade. Fill activities continue in the eastern half of the constructed area. The landfill has been constructed by area-fill techniques and contains



SITE LOCATION MAP

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LAIDLAW WASTE SYSTEMS 15550 68TH AVENUE COOPERSVILLE, MICHIGAN 49404	940387 FIGURE 1

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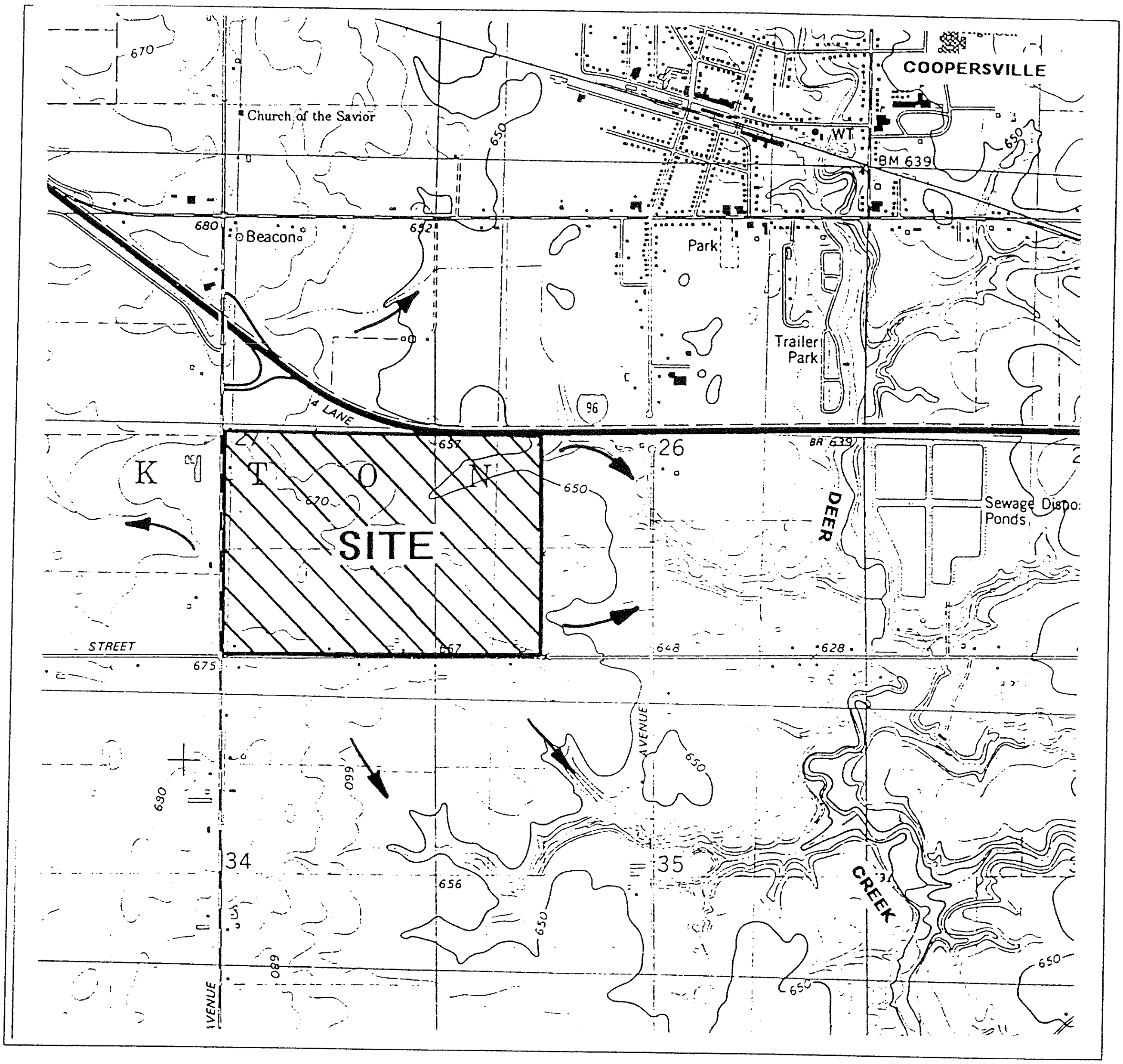
SURFACE DRAINAGE MAP



LEGEND

SURFACE DRAINAGE

0 0.5 1

SCALE (IN MILES)

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	FIGURE 2

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a leachate collection and removal system (LCRS) on a clay subgrade. Laidlaw has constructed and operated the landfill in accordance with all requirements imposed under former Act 641.

The unconstructed area south and east of Cells A through E has been redesigned and upgraded to meet the requirements of Part 115 (Dell, 1995a). The unconstructed area will be underlain by a composite liner consisting of a 60 mil HDPE geomembrane overlying a low-permeability clay subgrade. The composite liner will be overlain by the LCRS and a protective soils operation layer.

1.3 PROJECT DESCRIPTION

Dell conducted a hydrogeologic investigation at the Ottawa County Farms Landfill between July and September 1994. The key issues addressed are defined by Rule 904. The specific tasks conducted during the investigation and the items they address are presented below.

- An additional 20 borings were drilled to determine the glacial sediment and bedrock stratigraphy and to define water-bearing zones beneath the site.

- Soil samples were collected and tested to determine soil classification and undisturbed hydraulic conductivities.

- Twelve wells/piezometers were installed (two shallow, seven intermediate, and three deep) to determine groundwater flow direction, gradients (horizontal and vertical), and groundwater flow velocities.

- Aquifer testing was conducted at site piezometers and monitoring wells to determine the in-situ hydraulic properties of unconsolidated soil and bedrock units.

- Groundwater samples collected from the piezometers and monitoring wells were analyzed to determine existing groundwater quality and background quality.

2.0 REGIONAL GEOLOGY

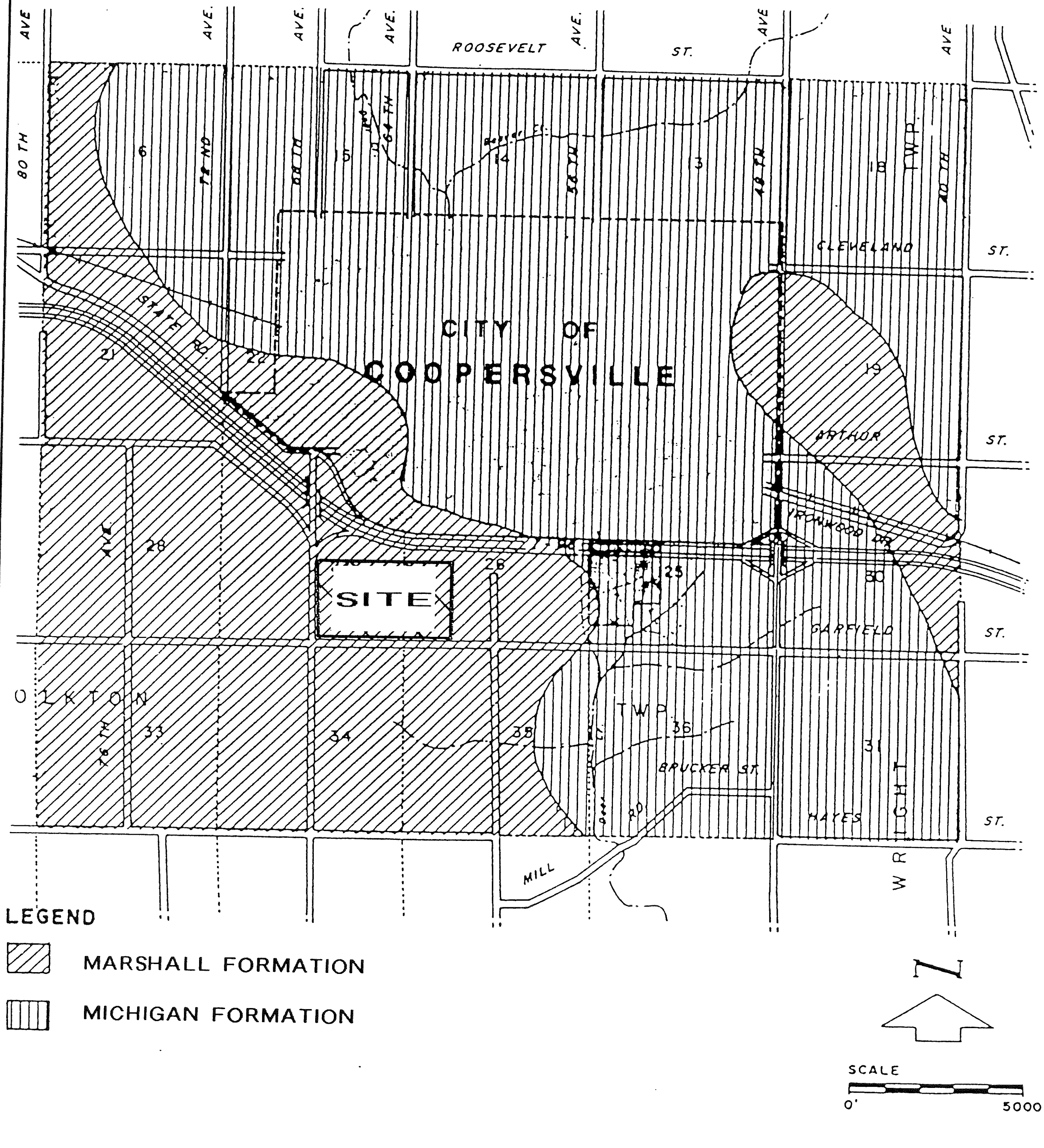
The regional geology provides an overview with which site geologic conditions are compared. The Ottawa County Farms Landfill is situated along the western part of the Michigan basin. The geology of the vicinity is shown in Figures 3 and 4, and is summarized from reports prepared by Western Michigan University (1981), Swain (1986), and Mandle and Westjohn (1988).

The western part of the basin is underlain by approximately 2,400 feet of consolidated sedimentary rocks which are mantled by as much as 400 feet of unconsolidated glacial sediments. The basin-fill sedimentary rocks are primarily shale, sandstone, and limestone which were deposited during the Mississippian period. There are no known active bedrock faults or other seismic sources in the region. Because of the limited thickness of the limestone bedrock, a karst terrain has not developed in the region. The unconsolidated glacial sediments consist of clay, silt, sand, and gravel which was deposited during the Wisconsin glacial stage. The regional characteristics of the sandstone bedrock and glacial sediments are discussed because they contain the primary aquifers beneath the site.

Sandstone bedrock beneath the site and east of the site is grouped with the Marshall Formation and parts of the overlying Michigan Formation (Figure 3). The regionally extensive sandstone units are approximately 200 to 300 feet thick and yield moderate quantities of freshwater. The Michigan Formation consists primarily of shale, gypsum, and limestone which yield limited quantities of groundwater.

Glacial sediments in the area unconformably overlie the bedrock formations and form part of the extensive north-south-trending Lake Border moranic system. Because of the limited topographic relief in the area, the glacial sediments are not susceptible to mass movement. The sediments consist of ground moraine, moraine, and outwash deposits (Figure 4). The moraine deposits consist primarily of massive beds of poorly-sorted silt and clay. These deposits typically restrict groundwater flow. Outwash deposits exposed east of the site (Figure 4) consist

REGIONAL BEDROCK GEOLOGY



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COOPERSVILLE, MICHIGAN

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FIGURE 3

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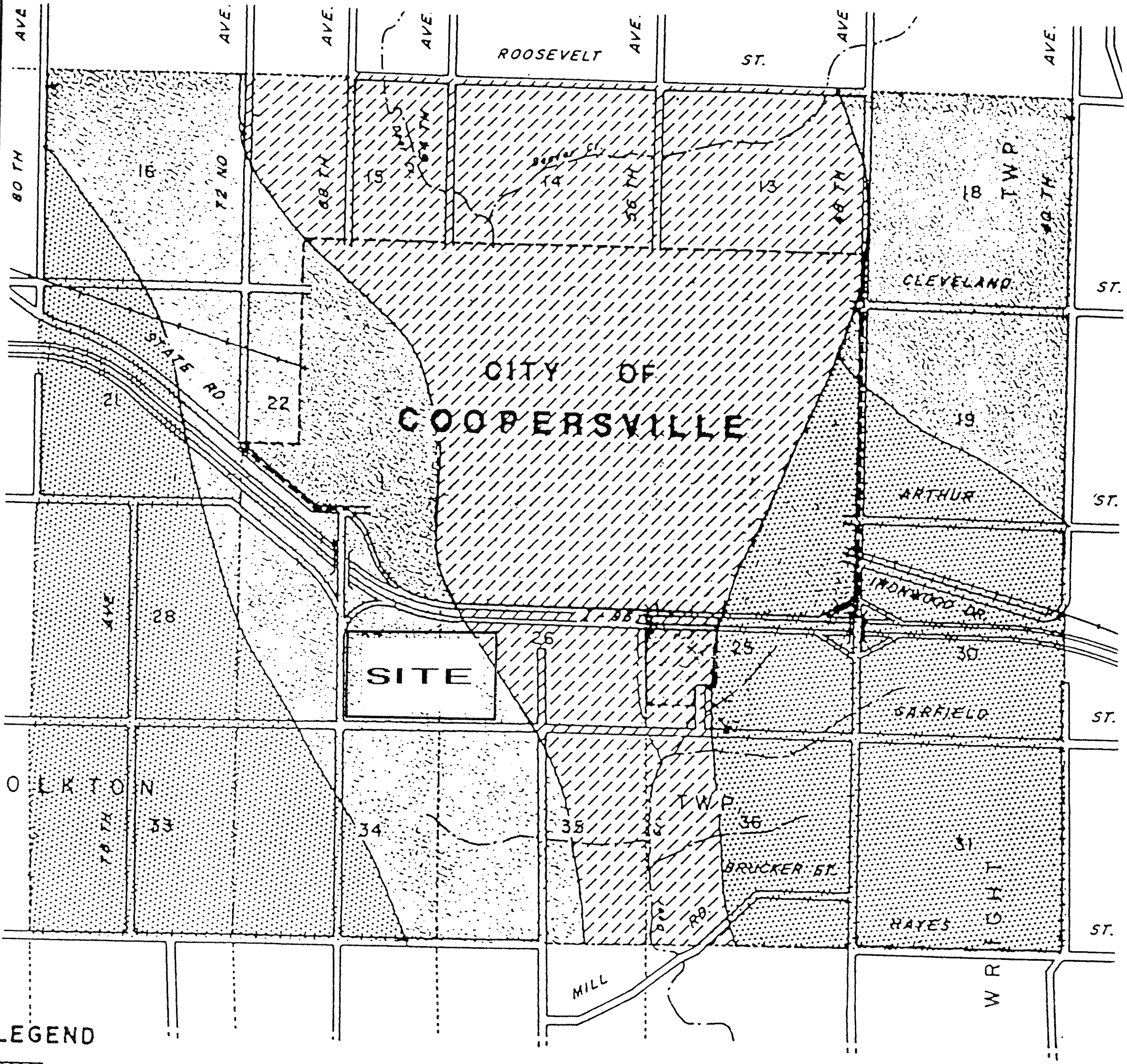
REGIONAL GLACIAL GEOLOGY



LEGEND

GROUND MORAINE

MORAINE

OUTWASH

N

SCALE

0' 5000'

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FIGURE 4

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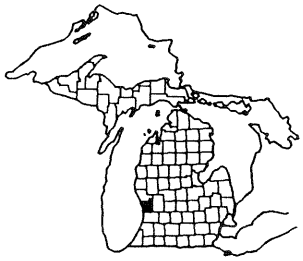
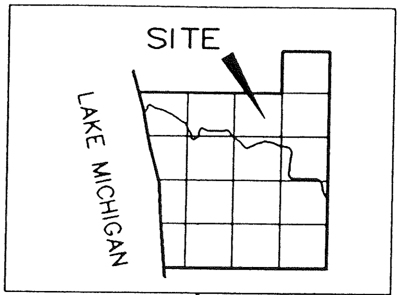
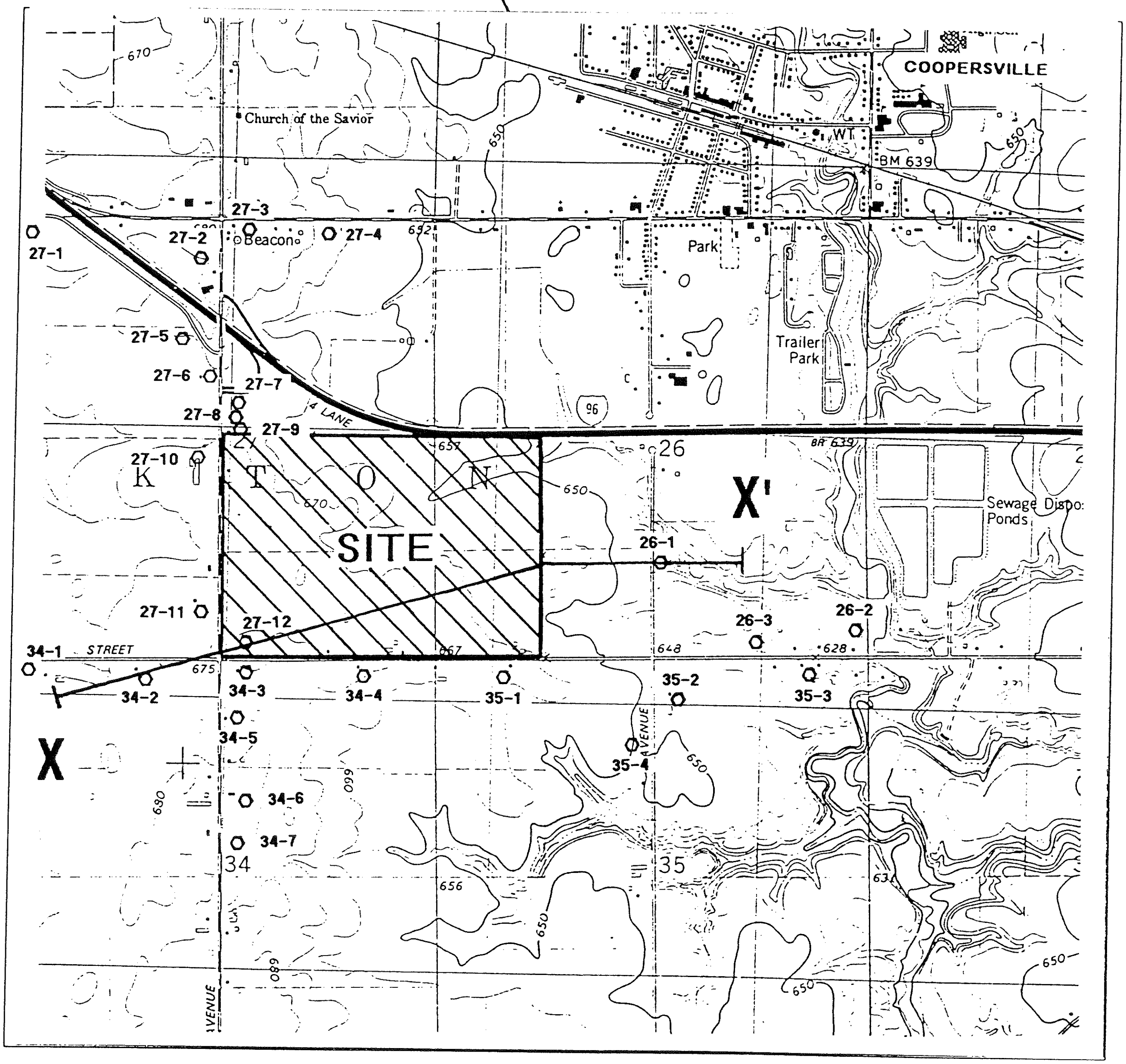
of well-sorted layers of silt, sand, and gravel. Similar sediments extend beneath the site (Figure 5) and contain the site's uppermost aquifer. These coarse-grained sediments typically contain limited aquifers in relatively small areas (Western Michigan University, 1981). None of these outwash deposits are regionally continuous. The regional glacial stratigraphy is in part, based on logs of water wells drilled within 0.5 mile of the site (Figure 6). Drillers' logs for these water wells are presented in Appendix A.





SECTIONS 26 & 27, T.8N, R.14W,
POLKTON TOWNSHIP,
OTTAWA COUNTY, MICHIGAN



WATER WELLS WITHIN 0.5 MILE OF SITE

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LAIDLAW WASTE SYSTEMS 15550 68TH AVENUE COOPERSVILLE, MICHIGAN 49404	940387 FIGURE 6

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3.0 SITE GEOLOGY

An evaluation of the site geology is required by Part 115 to characterize the areal and vertical extent of earth materials at the site. The evaluation is required because earth materials control site hydrogeologic and aquifer conditions. The geologic investigation focused on determining the depth to bedrock and the stratigraphy of the overlying glacial sediments. Methods used for this investigation are discussed first, followed by a discussion of bedrock and glacial stratigraphy.

3.1 Methods of Investigation

Exploratory drilling performed during this and previous investigations was used to evaluate the site geology. During this investigation, 20 exploratory borings were drilled around the perimeter of the facility (Figure 7). During previous site investigations, 40 exploratory borings were drilled around the perimeter of the site and beneath the existing landfill. An overview of the drilling and soil sampling procedures are presented in Appendix B and logs of exploratory borings are in Appendix C. The site map presented in Appendix C shows the location of exploratory borings drilled before this investigation.

3.2 Stratigraphy

Bedrock beneath the site consists of consolidated sedimentary rocks of the Marshall Formation. Surficial deposits at or near the site include glacial sediments, top soils, earth fill, and refuse fill. The subsurface distribution of these soil and bedrock units are illustrated in cross sections A-A' through D-D' (Figures 8 through 11). The results of soil classification testing are included on the cross sections. The following geologic descriptions are based on findings from the exploratory borings (Appendix C).

3.2.1 Bedrock

The Marshall Formation underlies the entire site at depth. The subsurface configuration of the bedrock surface was determined by the exploratory borings (Figures 8 through 11) and is relatively flat (Figure 5), dipping 1 to 2 degrees to the northeast. The upper part of Marshall Formation consists of a maximum of 20 feet of limestone that caps an unknown thickness of well-sorted, fine- to medium-grained quartz sandstone. The limestone is absent beneath the southwest portion of the site. The limestone contains vertical and horizontal fractures which are filled with pyrite. The extent and thickness of the limestone unit was determined from the exploratory borings and water well logs (Appendices A and C). The underlying sandstone unit is estimated to be approximately 200 to 300 feet thick (Mandle and Westjohn, 1988). The sandstone unit has moderate permeability and does not restrict groundwater flow. Groundwater conditions in the bedrock are discussed in Section 5.

3.2.2 Surficial Deposits

Surficial deposits consist of uncemented or weakly consolidated earth materials that have been reworked by natural or artificial means. At the site they include (1) refuse fill; (2) earth fill; and (3) glacial sediments, which include moraine and outwash deposits.

Refuse and earth fill refer to all cover soils, refuse, access roads, berms, and stockpiled earth materials within and directly adjacent to the site.

Glacial sediments are exposed around the perimeter of the site and underlie the entire site at depth. The glacial stratigraphy controls groundwater conditions in the uppermost aquifer. The following discussion is based on boring logs and drill core recovered from 60 exploratory borings drilled around the perimeter of the site and beneath the existing landfill (Appendix C).
The borings encountered approximately 190 to 205 feet of glacial sediments above the Marshall Formation. The contact between the glacial sediments and the underlying bedrock is not a barrier to groundwater flow beneath the eastern portion of the site (see Figures 8 and 11). The glacial

sediments consist of interbedded silt, sand, and gravel interlayered with massive beds of clay (Figure 5). The low-permeability clay beds restrict vertical groundwater movement. The sediments have been divided into four stratigraphic units based on their hydrogeologic characteristics; from top to bottom, they include an upper clay, upper sand, lower clay, and lower sand. A generalized description of each unit followed by its laboratory derived soil classification and approximate thickness are provided below.

The upper clay unit consists of massive clay beds (CL) interstratified with poorly-graded sand lenses (SP), which has a total thickness of 90 to 150 feet. The upper sand unit consists of poorly-graded, fine- to medium-grained sand and sandy silt beds (SP-SC), which have a total thickness of 5 to 55 feet. The lower clay unit consists primarily of sandy clay (SC) with minor silt (ML) and sandy silt lenses. The unit is discontinuous with a maximum thickness of approximately 60 feet beneath the northern portion of the site (cross section C-C'; Figure 10). The lower sand unit consists of poorly-graded, medium- to coarse-grained sand and includes a well-graded gravel (GW) to clayey gravel (GC) at the base of the section. The basal sand and gravel contains clasts derived from the underlying bedrock. The lower sand unit is discontinuous ranging from 20 to 35 feet thick beneath the eastern portion of the site (cross section D-D'; Figure 11). Beneath the southeastern portion of the site, the upper and lower sands form one unit approximately 55 feet thick.

The massive low-permeability clay units described above thicken to the west and are characteristic of sediments deposited in a moraine environment. The water-bearing sand units thin to the west and are characteristic of glacial outwash deposits. The upper sand is less than 5 feet thick beneath the southwestern part of the site, and the lower sand pinches out beneath the central part of the site (cross section A-A', Figure 8). The upper and lower sand units form one continuous stratigraphic unit beneath the southeastern part of the site. Exploratory borings drilled for water wells west of the site indicate that the water-bearing sands are absent downgradient from the site. Groundwater conditions in the glacial sediments are addressed in Section 5.

4.0 REGIONAL HYDROGEOLOGY

The regional hydrogeology provides an overview to which site conditions can be compared. The overview covers sufficient area to allow for a definition of the potential impact that site activities may have on groundwater. Hydrogeologic investigations of the Michigan basin and its associated regional aquifer systems have been performed by Western Michigan University (1981), Swain (1986), and Mandle and Westjohn (1988). The following is summarized from those reports.

Mississippian and Pennsylvanian sedimentary rocks and Quaternary sediments of the Michigan basin contain a regional aquifer system that consists of three primary aquifer units. These regional aquifer units include (1) a lower aquifer unit which is in sandstone of the Marshall and Michigan formations, (2) a middle aquifer unit which is in younger sedimentary rocks not present beneath the site, and (3) an upper aquifer unit which is in glacial sediments. The upper aquifer unit consists of numerous aquifers which are not regionally interconnected. Groundwater in the Marshall Formation and the glacial sediments is the focus of this investigation because they underlie the site. Regional groundwater flow in the Marshall Formation is generally from east to west consistent with topography in the western part of the basin. In the area surrounding the site, groundwater in the Marshall Formation generally flows west toward Lake Michigan (Mandle and Westjohn, 1988). Groundwater in the overlying glacial sediments generally flows southwest toward the Grand River drainage basin. Sewage disposal ponds for the City of Coopersville are located approximately 0.8 mile upgradient from the site, east of Deer Creek (Figure 2). The largest sources of natural recharge in the area are infiltration of rainfall, groundwater inflow from upgradient sources, and seepage from western tributaries of Deer Creek (Figure 2).

The Marshall Formation consists of locally fractured and cemented to poorly cemented sandstone with some limestone, shale, and siltstone. The bedrock is highly productive throughout the basin, supplying drinking water for both municipal and domestic needs. All of the known water wells within 0.5 mile of the site (Figure 6) are completed in the Marshall Formation except one, which is completed in the glacial sediments northwest of the site. The bedrock aquifer is typically enhanced by recharge from smaller, localized aquifers in the overlying glacial sediments and by surface water bodies. Transmissivity values for the Marshall aquifer where bedrock is hydraulically connected to the glacial sediments range from 130 to 27,000 square feet per day (ft^2/d) (Mandle and Westjohn, 1988). Glacial sediments in the vicinity of the site consist of outwash deposits interbedded with moraine deposits (Figures 4 and 5). The outwash deposits contain the most extensive aquifers in the glacial sediments. These deposits thicken to the east, upgradient from the site and pinchout to the west, downgradient from the site. Moraine deposits in the area consist of massive beds of clay that have low permeability and restrict groundwater flow. The clay beds thicken to the west, downgradient from the site. Water well logs from borings drilled adjacent to the site confirm the subsurface distribution of the glacial sediments (see cross section X-X'; Figure 5).

5.0 SITE HYDROGEOLOGY

The objectives of the hydrogeologic investigation are to satisfy the requirements of Rule 904. These objectives include defining the uppermost aquifer beneath the site and determining the flow paths and hydraulic characteristics of the water-bearing zone(s). Information from previous studies in conjunction with data obtained from this investigation were used to meet these objectives. The monitoring well network, groundwater occurrence, and conceptual hydrogeologic model are presented in the following sections.

5.1 MONITORING WELL NETWORK

The initial groundwater monitoring network consisted of four shallow observation wells (MW-1R, MW-2R, MW-11, and MW-12) installed between 1987 and 1993. The shallow wells are located in the northeastern part of the site (Figure 7) and are completed in the upper clay unit stratigraphically above the uppermost aquifer. Wells MW-1R and MW-2R are screened in discontinuous layers of sand and gravel and wells MW-11 and MW-12 are screened in clay interbedded with thin discontinuous layers of silt and sand (see cross sections C-C' and D-D'; Figures 10 and 11).

To define the uppermost aquifer consistent with Rule 904, four piezometers (DB-1, DB-2, DB-3, and DB-14) and eight monitoring wells (DB-5, DB-11, and DB-15 through DB-20) were installed during this investigation. Piezometer and monitoring well locations are shown in Figure 7, construction details and a survey data summary are presented in Tables 1 and 2, and details of the drilling and piezometer/well installation are included in Appendix B. To simplify further discussions, the new piezometers and monitoring wells are referred to as wells throughout the remainder of this report.

5.2 GROUNDWATER OCCURRENCE AND FLOW

Groundwater occurs in the sandstone bedrock and glacial sediments beneath the site.

TABLE 1

SUMMARY OF WELL CONSTRUCTION DETAILS

Laidlaw Waste Systems, Inc.
Ottawa County Farms Landfill
Coopersville, Michigan

MONITORING WELL AND PIEZOMETER IDENTIFICATION	DATE INSTALLED	AQUIFER OR WATER-BEARING UNIT SCREENED	TOTAL DEPTH (feet BGS)	WELL DIAMETER (inches)	BOREHOLE DIAMETER (inches)	WELL CONSTRUCTION MATERIALS	SCREENED INTERVAL (feet BGS)	SANDPACK INTERVAL (feet BGS)	SEAL INTERVAL (feet BGS)	GROUT INTERVAL (feet BGS)
DB-1 (Piezometer)	7/08/94	Lower Aquifer	213	2	9	Stainless Steel[1]	208-213	203-213	201-203	0-201
DB-2 (Piezometer)	7/15/94	Lower Aquifer	201	2	9	Stainless Steel[1]	196-201	190-210	180-190	0-180
DB-3 (Piezometer)	7/21/94	Lower Aquifer	206.5	2	9	Stainless Steel[1]	201.5-206.5	197.5-215	155-197.5	0-155
DB-5 (Monitoring Well)	7/12/94	Shallow	42.5	2	9	Schedule 40 PVC	37.5-42.5	34-42.5	31-34	0-31
DB-11 (Monitoring Well)	8/15/94	Upper Aquifer	107	2	9	Stainless Steel[1]	102-107	98-107	88-98	0-88
DB-14 (Piezometer)	8/02/94	Upper Aquifer	160	2	9	Stainless Steel[1]	155-160	151-167	141-151	0-141
DB-15 (Monitoring Well)	8/03/94	Shallow	48.5	2	9	Schedule 40 PVC	43.5-48.5	40-52	38-40	0-38
DB-16 (Monitoring Well)	8/12/94	Upper Aquifer	115	2	9	Stainless Steel[1]	110-115	107-117	104-107	0-107
DB-17 (Monitoring Well)	7/28/94	Upper Aquifer	152	2	9	Stainless Steel[1]	147-152	143-154	123-143	0-123
DB-18 (Monitoring Well)	9/26/94	Upper Aquifer	165	2	9	Stainless Steel[1]	160-165	157-174	147-157	0-147
DB-19 (Monitoring Well)	9/29/94	Upper Aquifer	148	2	9	Stainless Steel[1]	143-148	138-148	128-138	0-128
DB-20 (Monitoring Well)	10/03/94	Upper Aquifer	148	2	9	Stainless Steel[1]	143-148	140-148	136-140	0-136
MW-1R (Monitoring Well)	8/24/93	Shallow	79	2	9	Schedule 40 PVC	73-78	68-80	NA	0-68
MW-2R (Monitoring Well)	8/23/93	Shallow	79	2	9	Schedule 40 PVC	73-78	68-80	NA	0-68
MW-11 (Monitoring Well)	1/15/87	Shallow	22.5	2	9	Galvanized Steel[2]	17-19.5	9.5-19.5	0-9.5	0-9.5
MW-12 (Monitoring Well)	NA	Shallow	30.0	2	9	Galvanized Steel[3]	25-30	15-30	NA	0-15

NOTES:

BGS - Below Ground Surface
NA - Information not available
- [1] Well constructed with a stainless steel screen and 20 feet of stainless steel riser pipe, followed by a galvanized steel riser to the surface.
- [2] Screen material unknown
- [3] Well has a stainless steel screen with galvanized steel riser pipe.

TABLE 2

SUMMARY OF WELL SURVEY DATA

Laidlaw Waste Systems, Inc.
Ottawa County Farms Landfill
Coopersville, Michigan

WELL/PIEZOMETER IDENTIFICATION	NORTHING	EASTING	TOC ELEVATION (feet USGS)	GROUND ELEVATION (feet USGS)	SURVEY DATE	SURVEYOR
DB-1	7,017.7	1,288.0	672.66	670.2	08/94	Dell Engineering, Inc.
DB-2	4,660.7	3,499.9	669.46	666.6	08/94	Dell Engineering, Inc.
DB-3	5,908.0	4,925.1	661.74	658.9	08/94	Dell Engineering, Inc.
DB-5	4,530.0	1,882.4	678.57	675.7	08/94	Dell Engineering, Inc.
DB-11	6,912.4	4,136.9	652.92	650.3	08/94	Dell Engineering, Inc.
DB-14	7,024.5	1,277.9	673.19	671.1	08/94	Dell Engineering, Inc.
DB-15	7,014.6	1,274.7	673.37	671.8	08/94	Dell Engineering, Inc.
DB-16	5,919.3	4,924.2	660.96	659.0	08/94	Dell Engineering, Inc.
DB-17	4,546.8	1,243.6	679.65	677.2	08/94	Dell Engineering, Inc.
DB-18	6,109.2	1,217.3	675.87	673.42	10/94	Dell Engineering, Inc.
DB-19	4,533.7	2,413.1	678.57	676.48	10/94	Dell Engineering, Inc.
DB-20	5,157.7	1,219.5	673.75	672.06	10/94	Dell Engineering, Inc.
MW-1R	6,701.2	4,784.5	650.25	NA	09/02/93	Prein & Newhof, P.C.
MW-2R	6,497.0	4,916.7	652.49	NA	09/02/93	Prein & Newhof, P.C.
MW-11	6,200.2	3,633.8	653.38	652.3	09/02/93	Prein & Newhof, P.C.
MW-12	5,616.3	3,678.6	661.06	659.2	09/02/93	Prein & Newhof, P.C.

NOTES:

TOC - Top of Casing
USGS - Feet above mean sea level
NA - Information not available

Groundwater conditions in the bedrock have been evaluated by three deep wells (DB-1, DB-2, and DB-3). Conditions in the overlying glacial sediments which contain the uppermost aquifer have been evaluated by seven intermediate wells (DB-11, DB-14, and DB-16 through DB-20) and six shallow wells (DB-5, DB-15, MW-1R, MW-2R, MW-11, and MW-12). The shallow wells are completed in discontinuous sand and silt layers above the uppermost aquifer. The uppermost aquifer at the site, is approximately 90 and 150 feet below ground surface (BGS). The water-bearing sediments consist of well-sorted, fine- to medium-grained sand, which are approximately 30 feet thick along the eastern margin of the site and thin to less than 5 feet in the southwestern portion of the site (see cross sections A-A' and D-D'; Figures 8 and 11). Fractured limestone and sandstone beds of the Marshall Formation contain a lower aquifer approximately 190 to 205 feet BGS. The bedrock aquifer is several hundred feet thick (Mandle and Westjohn, 1988) and underlies the entire site.

The uppermost aquifer is hydraulically connected to the bedrock aquifer beneath the southeastern portion of the site. At this location, the lower clay unit is absent and the sand units which contain the uppermost aquifer are in direct contact with bedrock (see cross section A-A'; Figure 8).

Two deep wells (DB-1 and DB-3) and two intermediate wells (DB-14 and DB-16) (Figure 7) were installed adjacent to each other to form well pairs DB-1/DB-14 and DB-3/DB-16. The deep wells are screened in the bedrock aquifer and the adjacent intermediate wells are screened near the top of the uppermost aquifer (see cross section C-C'; Figure 10). The well pairs are constructed so that the upper and lower aquifers can be sampled independently and the vertical gradients between the aquifers can be determined. One shallow well DB-15 was added to the DB-1/DB-14 well pair to evaluate a water-bearing zone in the upper clay unit and to determine the vertical gradient between this water-bearing zone and the uppermost aquifer. Well DB-15 is screened across a discontinuous sand lens in the upper clay unit (see cross section B-B'; Figure 9).

Groundwater potentiometric elevations measured in the site wells on March 8, 1995, were used to generate the hydraulic head contours shown in Figures 12 and 13. These data were evaluated to determine the direction of groundwater flow beneath the site. Contours generated from the intermediate wells indicate that groundwater in the uppermost aquifer flows to the southwest (Figure 12). Contours generated from the deep wells indicate that groundwater in the lower aquifer flows to the northwest (Figure 13).

5.2.1 Shallow Wells

Six shallow wells (DB-5, DB-15, MW-1R, MW-2R, MW-11, and MW-12) are screened across thin discontinuous silt and sand lenses in the upper clay unit. The saturated silt and sand lenses are separated by thick layers of low-permeability clay and do not contain the site's uppermost aquifer. Groundwater in the clay unit was encountered 30 to 70 feet BGS and rose to within 10 to 15 feet BGS indicating it is confined or semiconfined by the low-permeability clay. Groundwater in this unit flows northeast, opposite to the flow in the uppermost aquifer (see Section 5.2.2). Northeast flow in the clay unit is consistent with site surface drainage which is generally toward the east into western tributaries of Deer Creek (Figure 2).

5.2.2 Upper Aquifer Wells

Intermediate wells DB-11, DB-14, and DB-16 through DB-20 are completed in the upper sand unit near the top of the uppermost aquifer, approximately 96 to 155 feet BGS. The groundwater potentiometric surface for the uppermost aquifer is approximately 26 to 61 feet BGS (see cross sections; Figures 8 and 11). The potentiometric surface is the elevation to which groundwater will rise due to confining conditions in the uppermost aquifer. The elevation of the hydraulic heads in these wells range from 627.00 feet USGS upgradient from the site to 619.03 feet USGS downgradient from the site. Contours generated from the intermediate wells indicate that groundwater in the uppermost aquifer flows southwest (Figure 12). Southwest flow is consistent with regional flow patterns, while northeast flow in the overlying clay unit is a local condition that occurs only within the discontinuous silt and sand lenses. The opposing flow directions beneath the site indicate that groundwater in the upper clay unit is not hydraulically connected with the uppermost aquifer.

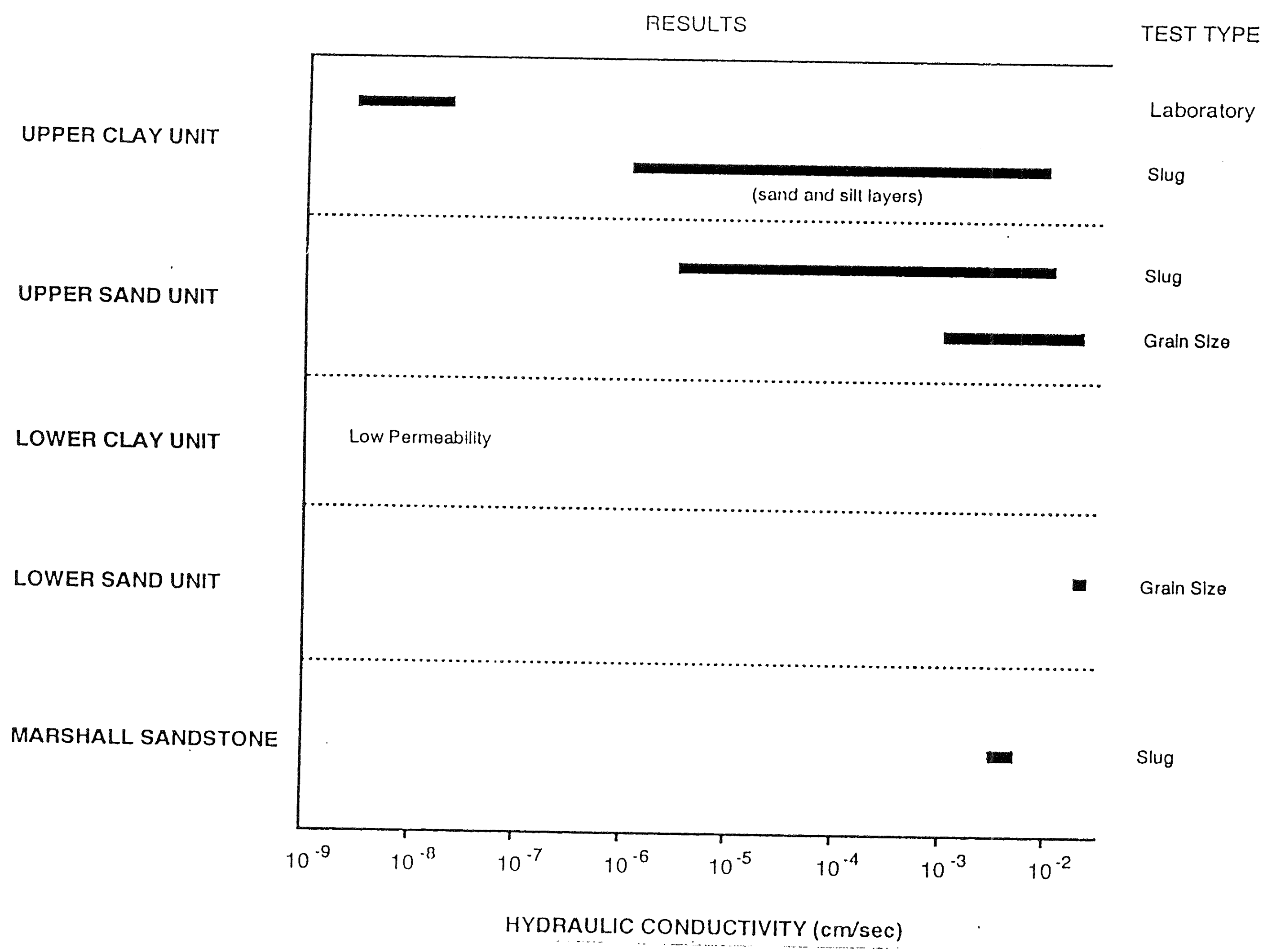
A domestic water well at 15616 68th Avenue, is completed in the uppermost aquifer cross gradient from the northwestern part of the site (see water well log 27-9; Appendix A).

5.2.3 Bedrock Wells

Deep wells DB-1, DB-2, and DB-3 are screened in sandstone bedrock of the Marshall Formation. The wells are completed near the top of this lower bedrock aquifer, approximately 196 to 208 feet BGS. The groundwater potentiometric surface for the lower aquifer is approximately 39 to 55 feet BGS (see cross sections B-B' and D-D'; Figures 9 and 11). Groundwater in the lower aquifer is confined. The elevation of the hydraulic heads in the deep wells range from 622.56 feet USGS in well DB-3 to 617.30 feet USGS in well DB-1. Contours generated from these wells indicate that groundwater in the lower aquifer unit flows northwest (Figure 13). The hydraulic head in well DB-1 varied from 612.96 feet USGS on August 17, 1994 to 611.80 feet USGS on August 26, 1994. Additional testing was performed in this well on September 1, 1994 to determine the range of hydraulic head elevations. During a 4.75 hour period, the hydraulic head varied 1.83 feet, from 613.15 to 614.98 feet USGS (Appendix D). The variance in hydraulic head is probably the result of aquifer drawdown from active farm and commercial wells completed in the lower aquifer west of the site (see water well logs 27-7 and 27-10; Appendix A). The cone(s) of depression produced by these water wells probably influences the direction of groundwater flow beneath the site.

5.2.4 Aquifer Hydraulic Characteristics

The aquifer testing program is summarized in this section and details of the testing methods and procedures are in Appendices B and D. The range of hydraulic conductivities in the glacial sediments and Marshall Formation are shown in Figure 14. These data were obtained from laboratory and slug testing and grain size analyses. A summary of the test results are presented in Table 3.



HYDRAULIC CONDUCTIVITY DATA COMPARISON

LAIDLAW WASTE SYSTEMS

15550 68TH AVENUE
COOPERSVILLE, MICHIGAN

940387

FIGURE 14

<940387-5> 40387H15 10/6/94

DELL ENGINEERING, INC. Civil Engineering • Environmental Consulting
3352 128th Avenue, Holland, Michigan 49424-9263

TABLE 3

HYDRAULIC CONDUCTIVITY DATA COMPARISON

Laidlaw Waste Systems
Ottawa County Farms Landfill
Coopersville, Michigan

PHYSICAL SOIL TESTING RESULTS (FLEX WALL – MODIFIED ASTM D5084)				
WELL IDENTIFICATION	SAMPLE INTERVAL (feet)	DESCRIPTION	UNIT	VERTICAL HYDRAULIC CONDUCTIVITY (cm/sec)
DB–1	28–30	CL – Sandy Lean Clay	Upper Clay	1.85E–08
DB–2	42–44	CL – Lean Clay with Sand	Upper Clay	1.31E–08
DB–3	54–56	CL – Sandy Lean Clay	Upper Clay	1.03E–08
DB–7	88–90	CL – Lean Clay with Sand	Upper Clay	3.25E–08
DB–13	60–62	CL – Sandy Lean Clay	Upper Clay	4.21E–09

HYDRAULIC CONDUCTIVITY ESTIMATED FROM GRAIN SIZE DISTRIBUTION				
WELL IDENTIFICATION	SAMPLE INTERVAL (feet)	DESCRIPTION	UNIT	HORIZONTAL HYDRAULIC CONDUCTIVITY (cm/sec)
DB–1	159–161	[SC] – Clayey Sand with Gravel	Upper Sand	1.0E–03
DB–2	135–137	SP – Poorly Graded Sand	Upper Sand	2.6E–02
DB–3	124–125	SP – Poorly Graded Sand	Upper Sand	6.8E–03
DB–3	182–184	[SP–SC] – Sand with Clay	Lower Sand	3.0E–02
DB–5	38–40	SP – Poorly Graded Sand	Upper Clay	1.6E–02
DB–11	102–104	[SP–SC] – Fine Sand with Clay	Upper Sand	3.5E–02
DB–17	149–151	[SP–SC] – Sand with Clay	Upper Sand	1.7E–02

HYDRAULIC CONDUCTIVITY FROM SLUG TEST RESULTS				
WELL IDENTIFICATION	SCREENED INTERVAL (feet)	SOIL TYPE AT SCREENED INTERVAL	UNIT	HORIZONTAL HYDRAULIC CONDUCTIVITY (cm/sec)
DB–1	208–213	Sandstone	Bedrock	5.70E–03
DB–2	196–201	Sandstone	Bedrock	5.10E–03
DB–3	201.5–206.5	Sandstone	Bedrock	5.56E–03
DB–5	37.5–42.5	Sand	Upper Clay	5.19E–03
DB–11	102–107	Sand	Upper Sand	1.76E–03
DB–14	155–160	Sand	Upper Sand	2.97E–03
DB–15	43.5–48.5	Sand	Upper Clay	9.49E–03
DB–16	110–115	Sand	Upper Sand	1.31E–02
DB–17	147–152	Sand	Upper Sand	5.08E–06
MW–11	17–19.5	Clay	Upper Clay	1.06E–06
MW–12	25–30	Clay	Upper Clay	2.69E–05
MW–2R	73–78	Sand with Gravel	Upper Clay	6.96E–03

[ ] – Brackets indicate that fines were assumed to be clay.

Rising- and falling-head slug tests were performed at twelve site wells (DB-1, DB-2, DB-3, DB-5, DB-11, DB-14 through DB-17, MW-11, MW-12, and MW-2R) to estimate the hydraulic conductivity of the saturated zone adjacent to the wells. Well MW-1R was not tested because the well casing was damaged and testing equipment could not be lowered into the well. A summary of the test results are presented in Table 3 and details of the aquifer testing are in Appendix D. Shelby tube samples collected from the glacial sediments were analyzed in the laboratory to determine their hydraulic properties and soil classification. Five samples were selected for laboratory testing. Their undisturbed hydraulic conductivities were determined in accordance with ASTM D5084 as modified by Part 115. A summary of the results is presented in Table 3 and details of the testing procedures are in Appendices B and E.

The hydraulic conductivity data has been compiled to evaluate the influence glacial sediments and bedrock have on groundwater flow. The following describes site conditions with respect to geologic units and aquifers.

5.2.4.1 Glacial sediments

The hydraulic conductivity values obtained from the glacial sediments are discussed with respect to the upper and lower clay and sand units.

Hydraulic conductivity values obtained from discontinuous sand, silt, and clay lenses in the upper clay unit were derived from slug tests performed in five shallow wells (DB-5, DB-15, MW-2R, MW-11, and MW-12). Hydraulic conductivity values obtained from the clay unit were also derived from laboratory testing of five shelby tube samples collected in borings DB-1, DB-2, DB-3, DB-7 and DB-13. Values obtained from the slug tests ranged from 9.49×10^{-3} to 1.06×10^{-6} centimeters per second (cm/sec) and values from the shelby tube samples ranged from 3.25×10^{-8} to 4.21×10^{-9} cm/sec (clay intervals) (Table 3) (Figure 14). Groundwater occurrence in the upper clay unit is restricted to thin discontinuous layers of silt and sand. Wells DB-5, DB-15, and MW-2R are screened across these layers. Values obtained from the slug tests performed in these wells range from 5.19×10^{-3} to 9.49×10^{3} cm/sec (Table 3). The higher values reflect the more permeable sand and silt layers. In contrast, values obtained from laboratory tests of clay samples and from slug tests in wells screened across clay beds (MW-11 and MW-12) ranged from 2.69 x 10^{-5} to 4.21 x 10^{-9} cm/sec (Table 3). These lower values are representative of the low-permeability properties of the upper clay unit.

Hydraulic conductivity values obtained from the upper sand unit (uppermost aquifer) were derived from slug tests preformed in four intermediate wells (DB-11, DB-14, DB-16, and DB-17). Hydraulic conductivity values for the uppermost aquifer ranged from 1.31 x 10^{-2} cm/sec in well DB-16 to 5.08 x 10^{-6} cm/sec in well DB-17 (Figure 14) (Table 3). The lower value obtained from well DB-17 represents a more clayey portion of the upper sand unit near where it pinches out downgradient from the site (Figure 8). Hydraulic conductivities estimated from the sieve analyses confirm the slug tests ranging from 3.5 x 10^{-2} to 1.0 x 10^{-3} cm/sec (Table 3).
Hydraulic conductivity values were not obtained for the lower clay unit but are expected to be similar to those obtained from the upper clay unit (Table 3).

A hydraulic conductivity value of 3.0 x 10^{-2} cm/sec (Figure 14) (Table 3) was determined for the lower sand unit based on sieve analyses (Appendix E). Slug tests were not performed in the lower sand because no wells are screened in this unit. Values ranging from 8.0 x 10^{-3} to 3.0 x 10^{1} cm/sec (Driscoll, 1986) are typical of gravelly sand.

5.2.4.2 Marshall formation

Hydraulic conductivity values obtained from sandstone bedrock of the Marshall Formation (lower aquifer) were derived from slug tests performed in three deep wells (DB-1, DB-2, and DB-3). Values obtained from the slug tests ranged from 5.70 x 10^{-3} to 5.10 x 10^{3} cm/sec (Figure 14) (Table 3) and transmissivity values ranged from 2,572 to 3,245 ft^2/d. These values are similar to those reported by Western Michigan University (1981) for a water well completed in the Marshall aquifer north of the site, in the City of Coopersville.

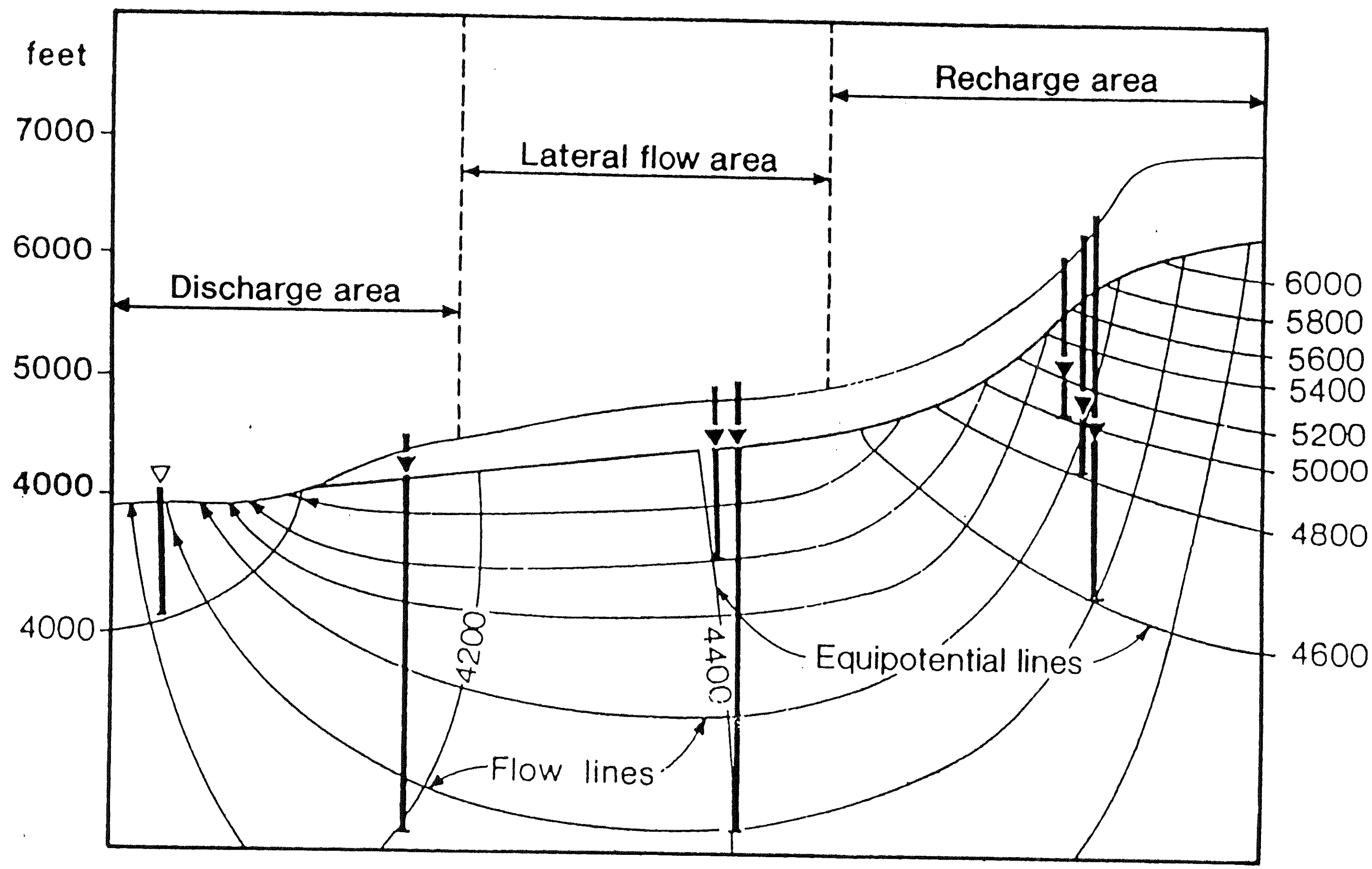
5.2.5 Vertical Hydraulic Gradient

The direction and rate of the vertical gradient beneath the site is required by Rule 904. This section addresses those requirements.

Aquifers are typically divided into areas of recharge, lateral flow, and discharge (Figure 15). In recharge areas, water has a downward component of movement because the hydrostatic pressure of the water column is greater than the hydraulic pressure of the aquifer. That is, the downward force of water in a recharge area is greater than the ability of an aquifer to support the water; and water moves down and away from the source of recharge. The recharge area illustrated in Figure 15 shows equipotential lines dipping away from the direction of horizontal flow. These conditions are similar to those observed at the site (Figure 16).

Vertical hydraulic gradients between the upper and lower aquifers underlying the site were evaluated at two locations by installing well pairs screened in each aquifer. Well pair DB-16/DB-3 is screened in the upper and lower aquifers upgradient from the site, and well pair DB-14/DB-1 is screened in the same aquifers downgradient from the site (Figures 10 and 11). The aquifers are hydraulically connected beneath the southeastern part of the site.

Vertical hydraulic gradients were calculated using water-level measurements taken October 6, 1994 (Table 4). The vertical hydraulic gradient for each well pair was estimated based on differences in potentiometric elevations of groundwater and the elevations of the screened intervals for each well pair. The groundwater elevation in well DB-16 (intermediate well) was 4.56 feet higher than that in adjacent well DB-3 (deep well) (Table 4), indicating a downward gradient in this location. Similarly, the groundwater elevation in well DB-14 (intermediate well) was 4.26 feet higher than that in adjacent well DB-1 (deep well) (Table 4), indicating a downward gradient in this location. The downward hydraulic gradient between the upper and lower aquifers was calculated to be 0.05 foot per foot (ft/ft) at well pair DB-16/DB-3 and 0.08 ft/ft at well pair DB-14/DB-1. The qualitative flow net in Figure 16 shows equipotential lines dipping away from the direction of flow, indicating a downward gradient. Gradients measured



CLASSIFICATION OF FLOW REGIME

MODIFIED FROM ERDELYI & GALFI (1988)

LAIDLAW WASTE SYSTEMS 15550 68TH AVENUE COOPERSVILLE, MICHIGAN	940387
DELL ENGINEERING, INC. Civil Engineering • Environmental Consulting 3352 128th Avenue, Holland, Michigan 49424-9263	FIGURE 15

<94 2> 4(3 10/
REVISIONS ARE TO BE MADE ON THE CADD FILE ONLY

TABLE 4

HISTORICAL GROUNDWATER ELEVATIONS

Laidlaw Waste Systems, Inc.
Ottawa County Farms Landfill
Coopersville, Michigan

WELL IDENTIFICATION	TOP OF CASING ELEVATION	GROUND SURFACE ELEVATION	GROUNDWATER ELEVATION (feet USGS)						
			09-23-93	08-17-94	08-26-94	10-06-94	12-01-94	01-30-95	03-08-95
DB-1	672.66	670.2	--	612.96	611.80	614.35	617.11	--	617.30
DB-2	669.46	666.6	--	618.95	619.19	619.89	620.93	--	621.11
DB-3	661.74	658.9	--	619.88	620.10	621.21	622.22	--	622.56
DB-5	678.57	675.7	--	670.14	670.13	669.65	670.57	672.12	671.91
DB-11	652.92	650.3	--	624.54	624.73	625.79	626.73	627.05	626.94
DB-14	673.19	671.1	--	617.35	617.50	618.61	--	--	--
DB-15	673.37	671.8	--	660.16	660.70	661.45	662.31	662.64	662.39
DB-16	660.96	659.0	--	624.52	624.72	625.77	626.74	627.11	627.00
DB-17	679.65	677.2	--	616.32	616.62	617.51	618.65	619.03	619.03
DB-18	675.87	673.42	--	--	--	618.14	619.27	619.77	619.69
DB-19	678.57	676.48	--	--	--	618.51	619.45	619.89	619.91
DB-20	673.75	672.06	--	--	--	617.57	618.97	619.38	619.38
MW-1R	650.25	--	623.91	--	--	625.75	--	627.05	627.02
MW-2R	652.49	--	623.93	--	--	625.78	626.72	627.23	627.09
MW-11	653.38	652.3	649.56	--	--	644.02	--	--	--
MW-12	661.06	659.2	656.54	--	--	656.74	--	--	--

NOTES:

USGS - Feet above mean sea level
-- - Data not available

beneath the site have remained relatively consistent since groundwater measurements began on August 17, 1994 (Table 4).

The vertical hydraulic gradient between the uppermost aquifer and a water-bearing zone in the overlying clay unit was evaluated at well cluster DB-15/DB-14/DB-1 using well pair DB-15/DB-14. Well DB-14 is screened in the uppermost aquifer and well DB-15 is screened in a discontinuous water-bearing sand lens in the overlying clay unit (see cross section B-B'; Figure 9). On October 6, 1994, the groundwater elevation in well DB-15 (shallow well) was 42.84 feet higher than that in adjacent well DB-1 (intermediate well) (Table 4), indicating a downward gradient. The uppermost aquifer and the water-bearing sand lens are not hydraulically connected beneath the site (see Section 5.2.2).

The time required for fluids to travel from the base of the landfill, through the upper clay unit, to the uppermost aquifer is calculated to be approximately 360 years (Dell, 1995a).

5.3 CONCEPTUAL HYDROGEOLOGIC MODEL

A conceptual hydrogeologic model of the site is presented in the following sections. The model is based on groundwater hydraulic head contours generated from historical groundwater elevations (Table 4) and data obtained from the aquifer and laboratory tests. The conceptual model is the foundation on which the site *Environmental Monitoring Plan* is based.

5.3.1 Groundwater Flow Direction

Groundwater in the site's bedrock aquifer flows northwest, and groundwater in the uppermost glacial sediment aquifer flows southwest, consistent with regional flow patterns (Mandle and Westjohn, 1988). The flow direction in the bedrock aquifer is probably influenced by aquifer drawdown produced by groundwater pumping from farm and commercial water wells completed in the same aquifer west of the site.

The qualitative flow net in Figure 16 illustrates the conceptual model for groundwater flow beneath the site. The flow net consists of equipotential lines of equal hydraulic head. The slope and direction of the lines were determined by the vertical hydraulic gradients established at the site's well pairs. The groundwater flow direction is perpendicular to the equipotential lines and is represented by the arrows (Figure 16). Groundwater in the upper and lower aquifers is confined and the aquifers are hydraulically connected. A comparison of groundwater flow in the aquifers is discussed below.

The hydraulic head contours and flow net indicate that groundwater moves under a slightly steeper hydraulic gradient in the upper sand unit (uppermost aquifer) than in the Marshall sandstone (lower aquifer). The horizontal gradient is 0.0025 ft/ft in the uppermost aquifer and 0.0014 ft/ft in the lower aquifer. The direction of groundwater flow in the uppermost aquifer is toward the southwest and flow in lower aquifer is toward the northwest (Figures 12 and 13). The vertical gradient across the aquifers is approximately 0.05 ft/ft downward along the eastern edge of the site and 0.08 ft/ft downward along the northwestern edge of the site. This means that, for every foot of vertical movement downward through the aquifers, the hydraulic head elevation falls approximately 0.05 to 0.08 foot.

5.3.2 Groundwater Flow Velocity

Groundwater flow velocities in the upper sand unit (uppermost aquifer) and in the Marshall sandstone (lower aquifer) were determined using groundwater elevations measured on March 8, 1995 and average hydraulic conductivities derived from aquifer tests.

The average flow velocity of groundwater in the sand and bedrock units was calculated from the following equation:

$$V = Ki/n_e$$

where V is the average flow velocity of groundwater, K is the hydraulic conductivity, i is the hydraulic gradient, and n_e is the effective porosity of the aquifer medium.

The average groundwater flow velocity for the upper sand unit was calculated using a hydraulic gradient of 0.0025 ft/ft and an average hydraulic conductivity of 7.68×10^{-4} cm/sec. Because the hydraulic conductivity values in an aquifer have the characteristics of log normal distributions and are distributed across several orders of magnitude, the "average" hydraulic conductivity is best described by the geometric mean (Domenico and Schwartz, 1990). The hydraulic conductivity used in this calculation is the geometric mean of the aquifer test results (Table 3) (Figure 14). An estimated effective porosity of 20 percent was selected for the sand unit based on data obtained from the soil testing program (Appendix E). The hydraulic gradient was calculated using the hydraulic head difference (7.09 feet) divided by the distance (2,850 feet) along the known flow direction (three-point problem using wells DB-16, DB-18, and DB-19). The average groundwater flow velocity in the uppermost aquifer is approximately 9.9 feet per year (ft/yr).

The average groundwater flow velocity for the Marshall sandstone was calculated using a hydraulic gradient of 0.0014 ft/ft and an average hydraulic conductivity of 5.45×10^{-3} cm/sec. The hydraulic conductivity used in this calculation is the geometric mean of the aquifer test results (Table 3) (Figure 14). An estimated effective porosity of 20 percent was selected for the sandstone based on literature sources (Driscoll, 1986). The hydraulic gradient was calculated using the hydraulic head difference (1.45 feet) divided by the distance (1,050 feet) along the known flow direction (three-point problem using wells DB-1, DB-2, and DB-3). The average groundwater flow velocity in the lower aquifer is approximately 39.5 ft/yr.

5.3.3 Summary of the Conceptual Hydrogeologic Model

Groundwater in the uppermost aquifer flows southwest with a average flow velocity of 9.9 ft/yr and groundwater in the lower bedrock aquifer flows northwest with an average flow velocity of 39.5 ft/yr. Communication between the upper and lower aquifers occurs as a result of a local downward hydraulic gradient.

6.0 SAMPLING AND ANALYSIS PROGRAM

Rule 904 requires a site investigation to determine the existing groundwater quality and background quality in the uppermost aquifer and aquifers that are hydraulically interconnected to the uppermost aquifer. To satisfy these requirements, Dell conducted a groundwater sampling and analysis program at the site. Results of the program are presented in this section.

6.1 GROUNDWATER QUALITY

Groundwater samples were collected from wells DB-1, DB-2, DB-3, DB-5, DB-11, and DB-14 through DB-17 on August 26, 1994 to assess the existing groundwater quality in the shallow water-bearing zone, and the upper and lower aquifers. Well locations are shown in Figure 7 and details of the sampling procedures are in *Environmental Monitoring Plan* (Dell, 1995b). Field data sheets documenting the sampling event are presented in Appendix F. To determine the existing groundwater quality, samples were analyzed for the primary and alternate inorganic indicators (Table 5), heavy metals (Table 6), and the primary and secondary volatile organic constituents (VOCs) by U.S. Environmental Protection Agency (EPA) method 8240. The inorganic indicators analyzed for included chloride, iron, sulfate, total inorganic nitrogen, total dissolved solids, magnesium, potassium, sodium, bicarbonate alkalinity, carbonate alkalinity, total organic carbon, and chemical oxygen demand. The heavy metals analyzed for included antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, thallium, vanadium, and zinc. Analytical results and chain-of-custody documentation are in Appendix F. Results of the groundwater analysis program indicate that the shallow water-bearing zone and the upper and lower aquifers have not been impacted by landfill activities. A summary of the results is presented below.

Groundwater samples collected from wells DB-1, DB-2, DB-3, DB-5, DB-11, and DB-14 through DB-17 contained no detectable VOCs (Appendix F).

TABLE 5

PRIMARY AND ALTERNATE INORGANIC INDICATORS

Laidlaw Waste Systems
Ottawa County Farms Landfill
Coopersville, Michigan

STRATIGRAPHIC UNIT	GLACIAL SEDIMENTS						SANDSTONE BEDROCK				
	SHALLOW PIEZOMETERS		INTERMEDIATE PIEZOMETERS UPPER AQUIFER				DEEP PIEZOMETERS LOWER AQUIFER				
SAMPLE DESCRIPTION	DB–5	DB–16	DB–11	DB–14	DB–16	DB–17	DB–1	DB–2	DB–3	MRL	UNITS
Chloride	11	38	26	5.8	5.0	5.1	9.0	4.9	4.0	1.0	mg/l
Iron	71	110	270	640	970	37	1260	1510	930	20	ug/l
Sulfate	407	265	444	416	309	113	850	330	948	2.0	mg/l
Inorganic Nitrogen	0.61	0.79	0.89	0.72	0.49	4.8	0.41	0.51	0.49	0.05	mg/l
Nitrate Nitrogen	0.02	0.01	–	–	0.02	0.02	–	–	–	0.01	mg/l
Ammonia Nitrogen	0.58	0.72	0.87	0.70	0.45	4.8	0.39	0.49	0.48	0.01	mg/l
Nitrate Nitrogen	0.01	0.06	0.02	0.02	0.02	–	0.02	0.02	0.01	0.01	mg/l
Dissolved Solids	1080	645	912	728	667	3240	1490	714	1570	20	mg/l
Magnesium	101	6.5	19	28	25	–	36	25	33	1.0	mg/l
Calcium	80	9.2	98	121	127	330	304	146	353	1.0	mg/l
Potassium	7.2	109	112	5.2	3.2	490	4.5	3.2	4.2	0.10	mg/l
Sodium	126	110	99	66	36	419	53	36	43	1.0	mg/l
Bicarbonate Alkalinity	622	19	173	96	222	–	165	229	175	5.0	mg/l
Carbonate Alkalinity	–	161	–	–	–	120	–	–	–	10	mg/l
Total Organic Carbon	2.1	2.7	3.2	2.3	1.1	8.5	0.69	0.70	0.69	0.5	mg/l
Chemical Oxygen Demand	7.3	76	14	7.1	–	3.4	–	–	–	5.0	mg/l
Turbidity	180	4550	49	190	350	70	7.4	20	38	1.0	NTU's
pH	12.69	8.29	10.96	6.44	7.41	8.87	6.09	7.38	7.54		

NOTES:

1. MRL = Method Reporting Limit
2. – = Not Detected
3. mg/l = milligrams per liter
4. ug/l = micrograms per liter
5. NTU's = Nephelometric Turbidity Units

TABLE 6

HEAVY METALS

Laidlaw Waste Systems
Ottawa County Farms Landfill
Coopersville, Michigan

STRATIGRAPHIC UNIT	GLACIAL SEDIMENTS						SANDSTONE BEDROCK				
	SHALLOW PIEZOMETERS		INTERMEDIATE PIEZOMETERS UPPER AQUIFER				DEEP PIEZOMETERS LOWER AQUIFER				
SAMPLE DESCRIPTION	DB-5	DB-16	DB-11	DB-14	DB-16	DB-17	DB-1	DB-2	DB-3	MRL	UNITS
Antimony	–	–	–	–	–	–	4.2	–	–	2.0	ug/l
Arsenic	3.8	4.7	5.7	1.7	7.0	1.0	4.8	1.3	4.5	1.0	ug/l
Barium	31	20	25	29	17	400	–	16	13	1.0	ug/l
Beryllium	–	–	–	–	–	–	–	–	–	1.0	ug/l
Cadmium	–	0.3	–	–	–	–	–	–	–	2.0	ug/l
Chromium	–	–	–	–	–	–	–	–	–	1.0	ug/l
Cobalt	–	–	–	–	–	–	–	–	–	15	ug/l
Copper	1.8	2.3	–	–	–	11	–	–	–	1.0	ug/l
Lead	3.0	–	–	–	–	294	–	–	–	1.0	ug/l
Nickel	–	–	–	–	–	–	–	–	–	50	ug/l
Selenium	–	–	2.4	–	–	–	–	–	–	1.0	ug/l
Silver	–	–	–	–	–	–	–	–	–	0.5	ug/l
Thallium	–	–	–	–	–	–	–	–	–	2.0	ug/l
Vanadium	–	–	–	–	–	–	–	–	–	10	ug/l
Zinc	340	34	22	130	140	340	220	93	46	4.0	ug/l

NOTES:

1. MRL = Method Reporting Limit

2. – = Not Detected

3. ug/l = micrograms per liter

Samples collected from the wells were analyzed for the primary and alternate inorganic indicators. Distinct patterns related to geologic formations are observed in the geochemistry data indicating a spatial variation in groundwater chemistry beneath the site. The shallow and intermediate wells completed in the glacial sediments typically contain lower concentrations of iron, magnesium, calcium, sulfate, and total dissolved solids than do the wells completed in the sandstone bedrock (Table 5). Lower concentrations for sulfate, dissolved solids, and calcium are also observed in deep well DB-2 (Table 5) and are probably the result of uppermost aquifer waters mixing with the lower aquifer. The aquifers are interconnected at this location, and groundwater flow is controlled by a downward gradient (Section 5).

Samples collected from the site's wells were analyzed for fifteen heavy metals. Eight metals were detected in the samples (Table 6). Five metals (antimony, arsenic, cadmium, copper, and selenium) were detected at low levels, at or below 11 micrograms per liter (μg/l). Two metals (arsenic and zinc) were detected in all of the wells (Table 6). Relative to other site wells, higher concentrations of barium (400 μg/l), lead (294 μg/l), and zinc (340 μg/l) were detected in a sample collected from well DB-17 (Table 6). The sample also contained higher concentrations of inorganic nitrogen (4.8 milligrams per liter [mg/l]), ammonia nitrogen (4.8 mg/l), total dissolved solids (3240 mg/l), calcium (330 mg/l), potassium (490 mg/l), sodium (419 mg/l), alkalinity carbonate (120 mg/l), and total organic carbon (Table 5). The higher values may be associated with grout fluids used to seal the bottom of the boring (Appendix B).

Well DB-17 was purged on October 5, 1994 to determine if waters adjacent to the well have mixed with grout fluids. During the purging event, a groundwater grab sample was collected every 4 to 5 minutes (2 to 3 gallons). The samples were tested in the field to determine conductivity, total dissolved solids, temperature, and pH (Appendix C). Total dissolved solids and conductivity decreased and temperature and pH increased during the purging event indicating that formation waters have been influenced by grout. Additional groundwater chemistry data from future sampling events, combined with this data, is intended to establish background groundwater quality in the upper and lower aquifers.

7.0 SUMMARY

The intent of this investigation was to address Part 115 regarding surface and subsurface conditions at the site through hydrogeologic characterization. Key items noted in Part 115 include (1) determining the soil and bedrock stratigraphy beneath the site, (2) identifying the uppermost aquifer and aquifers that are hydraulically interconnected to the uppermost aquifer, (3) defining the hydraulic properties of the soil and bedrock units, (4) determining the groundwater flow direction, flow rates, and the vertical and horizontal gradients, and (5) determining existing and background groundwater quality in the uppermost aquifer. The observations and findings that address the hydrogeologic conditions are summarized below.

- The glacial and bedrock stratigraphy was determined by twenty exploratory borings. Bedrock consists of limestone and sandstone of the Marshall Formation which is overlain by approximately 200 feet of glacial sediments. The glacial sediments are divided into four stratigraphic units based on their hydrogeologic characteristics. From top to bottom they include (1) an upper clay unit approximately 90 to 150 feet thick, (2) an upper sand unit approximately 5 to 55 feet thick, (3) a lower discontinuous clay unit which has a maximum thickness of approximately 60 feet, and (4) a lower discontinuous sand unit which has a maximum thickness of approximately 25 feet.

- Sedimentary rocks of the Marshall Formation have moderate permeability and contain a regional aquifer which is an estimated 200 to 300 feet thick. This bedrock aquifer is the lowermost aquifer at the site. A sand unit in the overlying glacial sediments contains the uppermost aquifer at the site. The sand unit has moderate permeability and is hydraulically interconnected with the lower aquifer beneath the southeast portion of the site.

- Groundwater in the lower aquifer flows northwest and groundwater in the uppermost aquifer flows southwest. Groundwater flow in the lower aquifer is probably influenced by extensive groundwater pumping from farm and commercial water wells west of the site.

- The site is in an aquifer recharge area characterized by downward hydraulic gradients. Groundwater in the lower and upper aquifers moves under a similar hydraulic gradient which ranges from 0.0014 to 0.0025 ft/ft. The average groundwater flow velocity in the lower aquifer is 39.5 ft/yr and the average flow velocity in the uppermost aquifer is 9.9 ft/yr.

- Groundwater samples collected from site wells did not contain detectable amounts of VOCs. Groundwater at the site has not been impacted by landfill activities.

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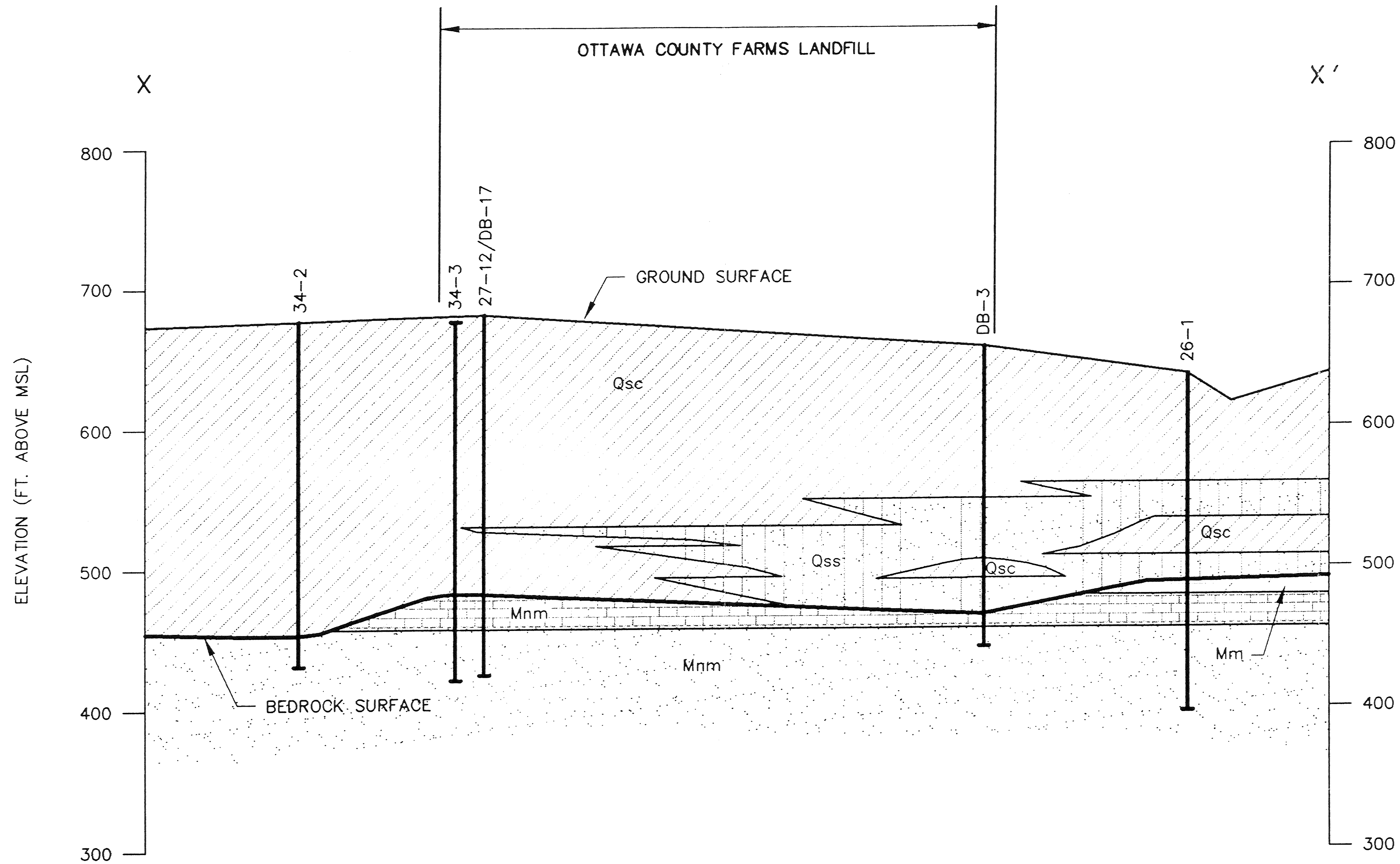
REGIONAL GEOLOGIC CROSS SECTION



SCALE
HORIZONTAL : 1"=1000'
VERTICAL : 1"=100'

LEGEND

Qsc	CLAY	Mm	MICHIGAN FORMATION; GYPSUM & SHALE
Qss	SILT, SAND & GRAVEL	Mnm	MARSHALL FORMATION; LIMESTONE & SANDSTONE

NOTE:
SEE FIGURE 6 FOR LOCATION OF CROSS SECTION

<940387-2> 40387H12 10/11/94
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LAIDLAW WASTE SYSTEMS
15550 68TH AVENUE
COOPERSVILLE, MICHIGAN

940387

FIGURE 5

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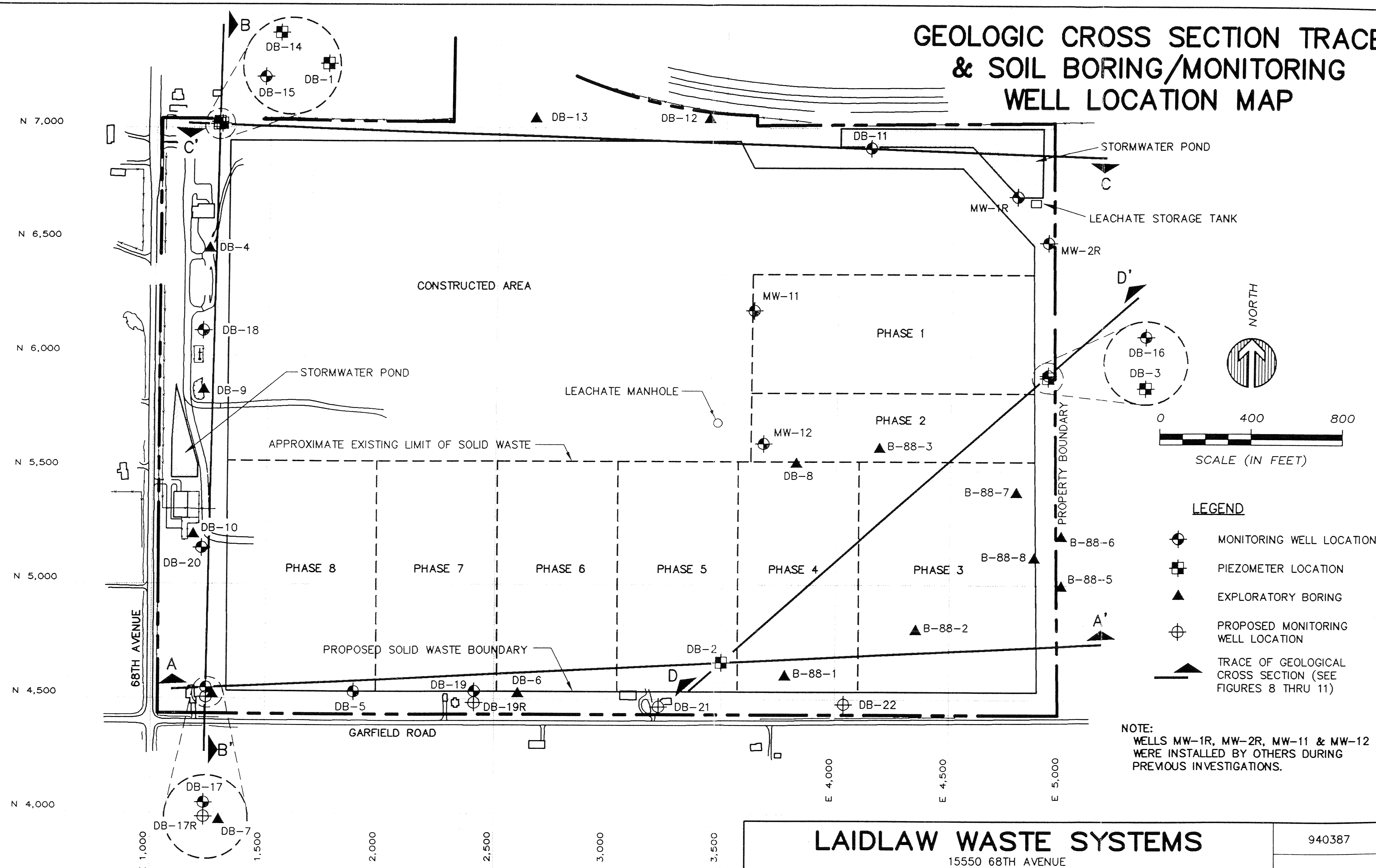
GEOLOGIC CROSS SECTION TRACE & SOIL BORING/MONITORING WELL LOCATION MAP



NOTE:
WELLS MW-1R, MW-2R, MW-11 & MW-12 WERE INSTALLED BY OTHERS DURING PREVIOUS INVESTIGATIONS.

<940387-4> 40387H06 8/28/95
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LAIDLAW WASTE SYSTEMS 15550 68TH AVENUE COOPERSVILLE, MICHIGAN 49404	940387
	FIGURE 7

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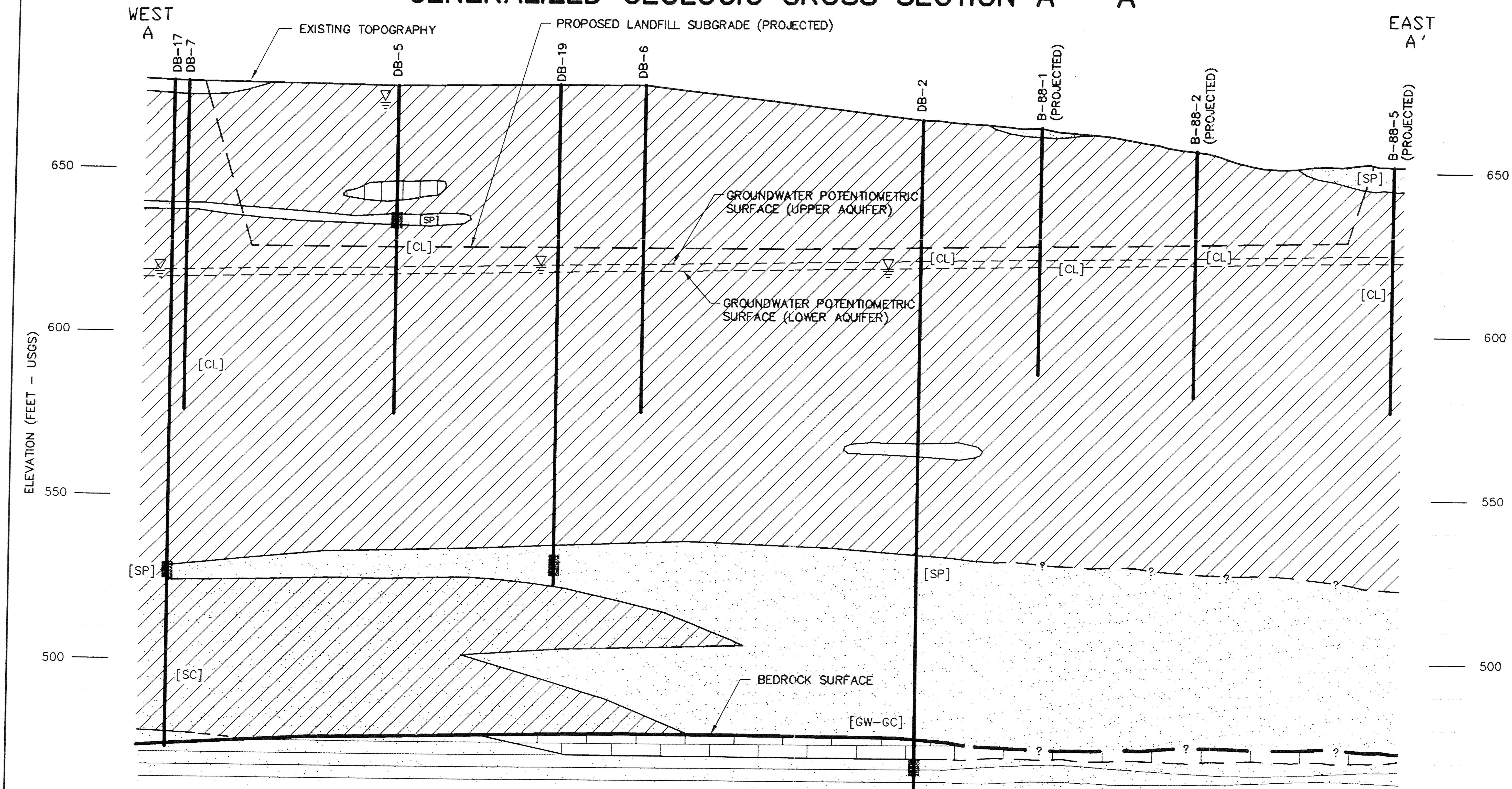
GENERALIZED GEOLOGIC CROSS SECTION A – A'



LEGEND

SAND

CLAY

SILT

LIMESTONE

SANDSTONE

SCREENED INTERVAL

STATIC WATER LEVEL MEASURED MARCH 8, 1995

NOTES:

1. SEE FIGURE 7 FOR LOCATION OF CROSS SECTION
2. SEE FIGURE 9 FOR DESCRIPTION OF SOIL UNITS
3. PROPOSED LANDFILL SUBGRADE IS BASED ON ENGINEERING PLANS (DELL ENGINEERING, INC. 1995)

SCALE
HORIZONTAL : 1"=300'
VERTICAL : 1"=30'

<940387-4> 40387H07 8/28/95
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LAIDLAW WASTE SYSTEMS 15550 68TH STREET COOPERSVILLE, MICHIGAN	940387
	FIGURE 8

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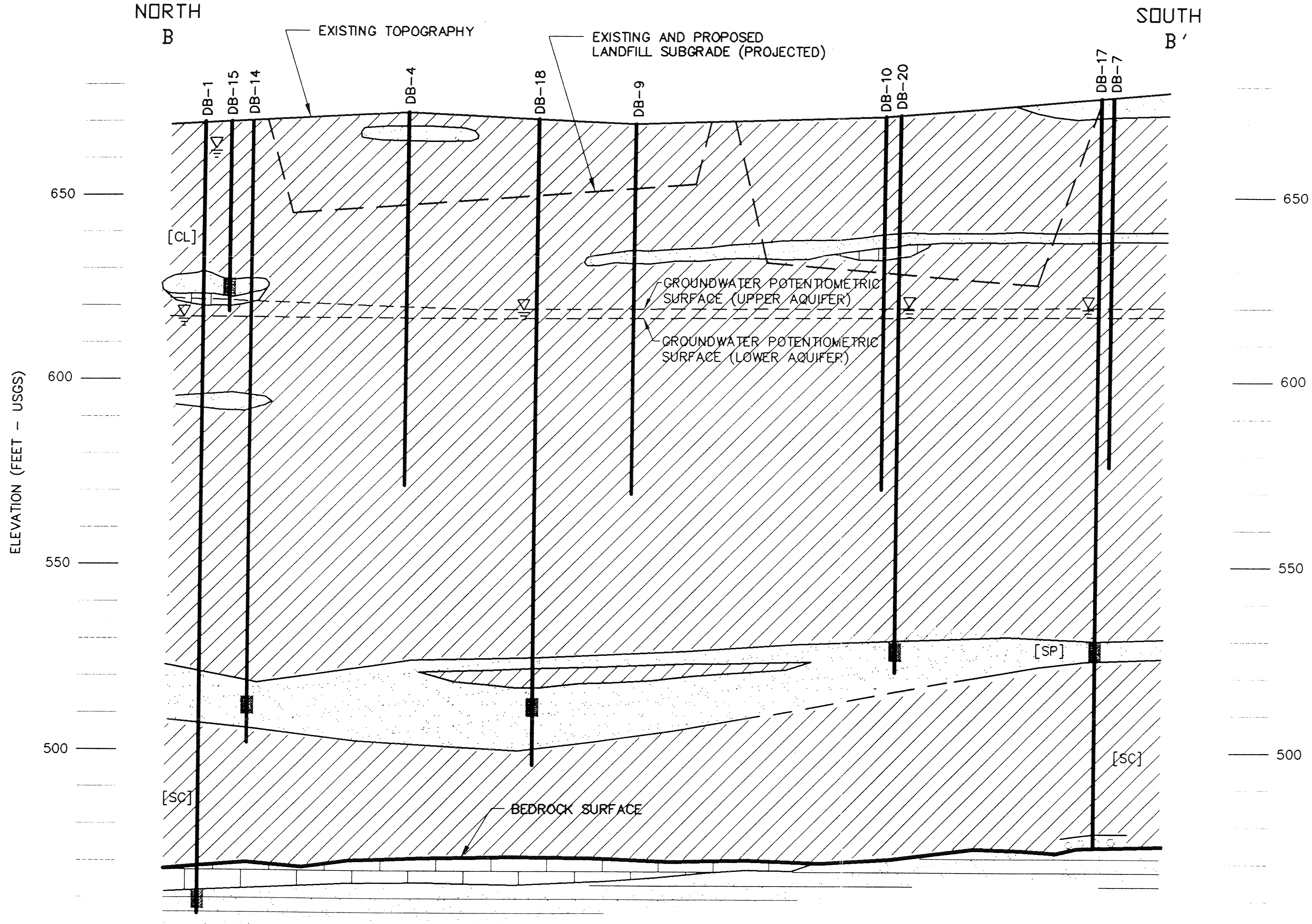
GENERALIZED GEOLOGIC CROSS SECTION B – B'



SCALE
HORIZONTAL : 1"=300'
VERTICAL : 1"=30'

LEGEND

- SAND
- CLAY
- SILT
- LIMESTONE
- SANDSTONE
- STATIC WATER LEVEL MEASURED MARCH 8, 1995
- SCREENED INTERVAL

[GW] WELL-GRADED GRAVEL
[GC] CLAYEY GRAVEL
[SP] POORLY-GRADED SAND
[SM] SILTY SAND
[SC] CLAYEY SAND
[ML] SILT (LOW PLASTICITY)
[CL] CLAY (LOW PLASTICITY)

NOTES:
1. SEE FIGURE 7 FOR LOCATION OF CROSS SECTION
2. PROPOSED LANDFILL SUBGRADE IS BASED ON ENGINEERING PLANS (DELL ENGINEERING, INC. 1995)

<940387-4> 40387H08 8/15/95
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LAIDLAW WASTE SYSTEMS
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COOPERSVILLE, MICHIGAN

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FIGURE 9

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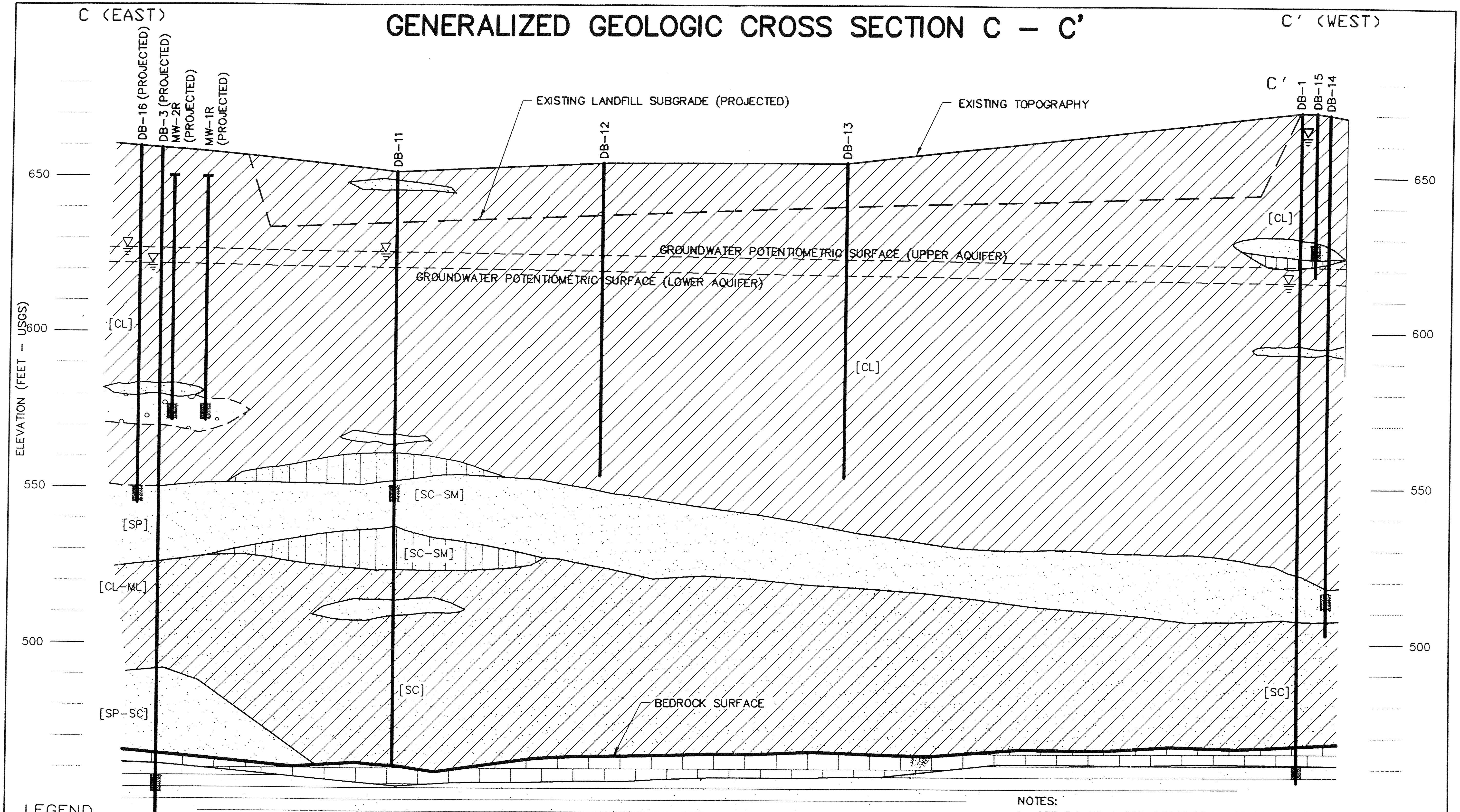
GENERALIZED GEOLOGIC CROSS SECTION C – C'



NOTES:
1. SEE FIGURE 9 FOR DESCRIPTION OF SOIL UNITS
2. SEE FIGURE 7 FOR LOCATION OF CROSS SECTIONS

LEGEND

SAND
SILT
SANDSTONE
CLAY
LIMESTONE
SCREENED INTERVAL
STATIC WATER LEVEL MEASURED MARCH 8, 1995

SCALE
HORIZONTAL : 1"=300'
VERTICAL : 1"=30'

<940387-4> 40387H09 8/15/95
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LAIDLAW WASTE SYSTEMS
15550 68TH STREET
COOPERSVILLE, MICHIGAN

940387

FIGURE 10

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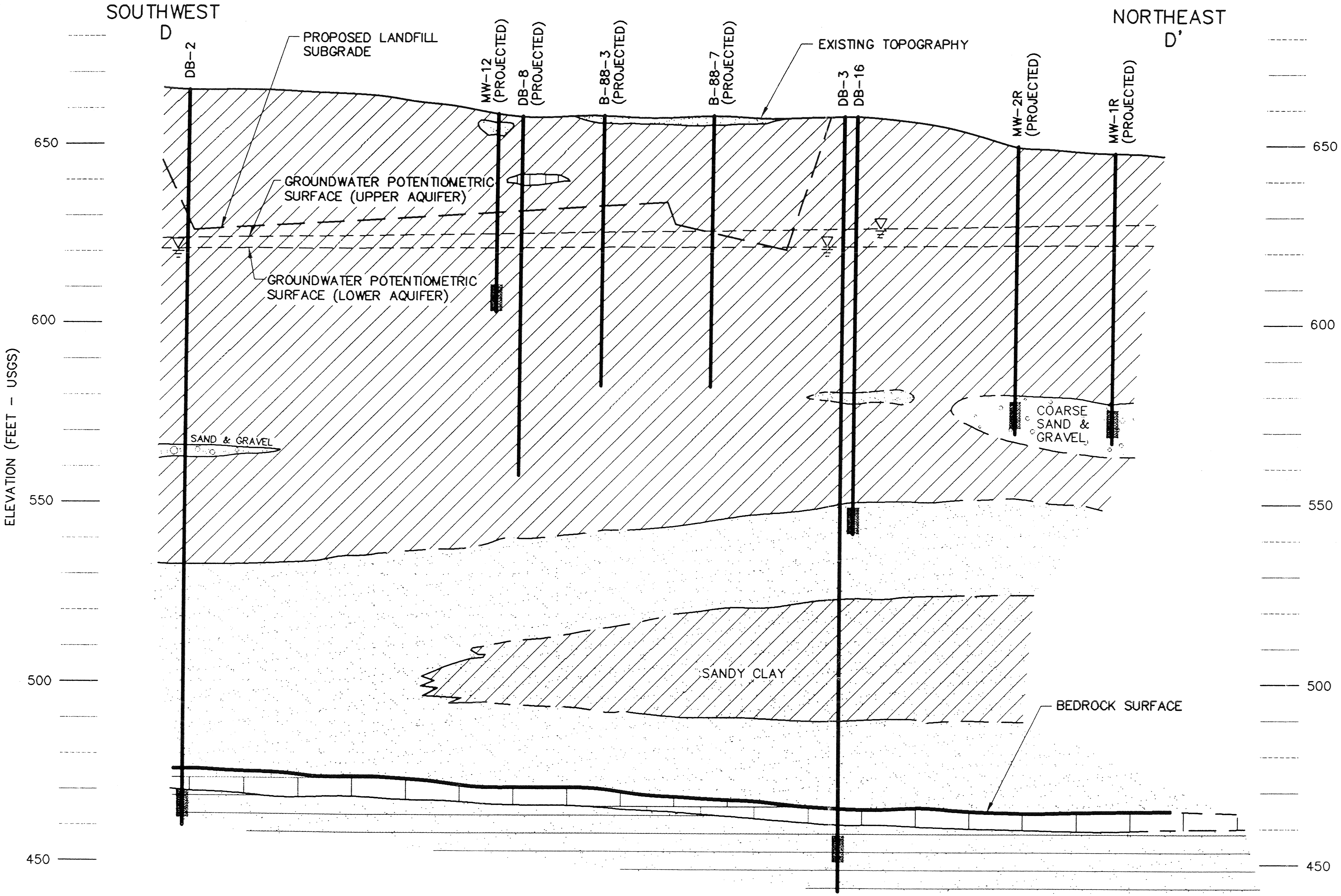
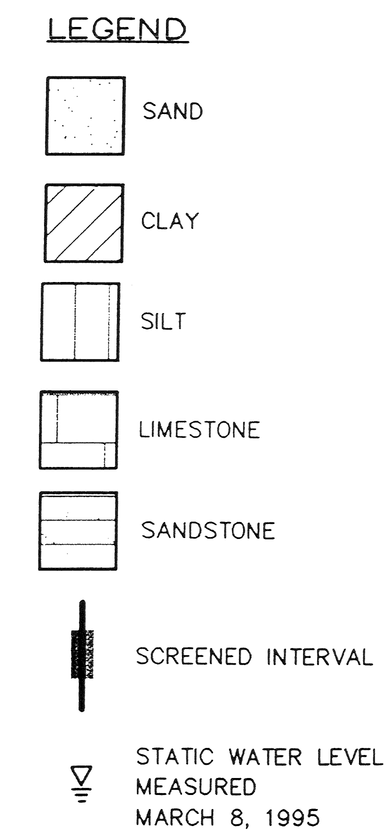
GENERALIZED GEOLOGIC CROSS SECTION D – D'





NOTES:

1. SEE FIGURE 9 FOR DESCRIPTION OF SOIL UNITS
2. SEE FIGURE 7 FOR LOCATION OF CROSS SECTION

SCALE
HORIZONTAL : 1"=300'
VERTICAL : 1"=30'

<940387-5> 40387H10 8/16/95
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LAIDLAW WASTE SYSTEMS 15550 68TH STREET COOPERSVILLE, MICHIGAN	940387
	FIGURE 11

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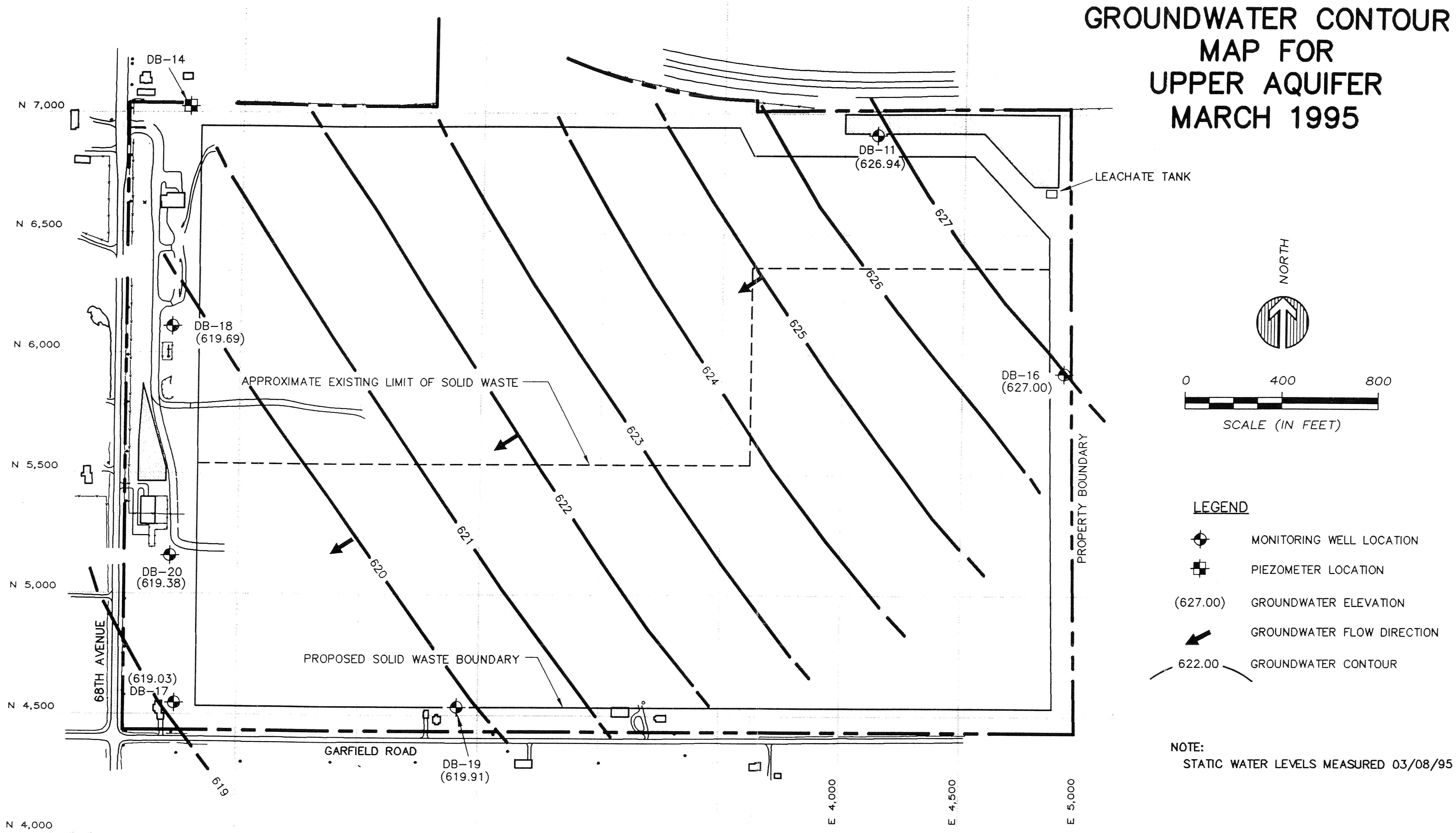

<940387-2> 40387H03 8/29/95
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LAIDLAW WASTE SYSTEMS 15550 68TH STREET COOPERSVILLE, MICHIGAN	940387 FIGURE 12

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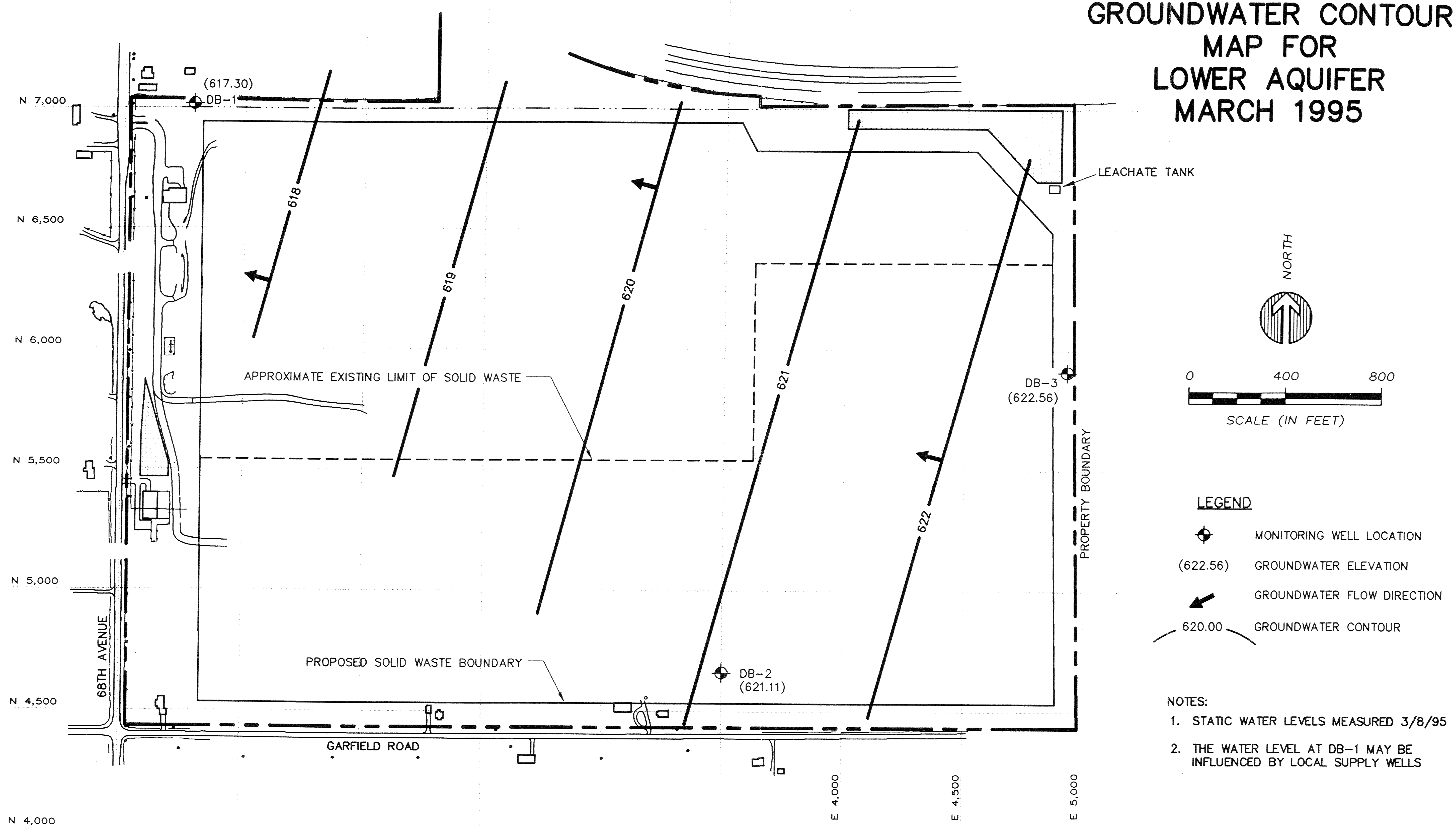
GROUNDWATER CONTOUR MAP FOR LOWER AQUIFER MARCH 1995



LEGEND

⌖	MONITORING WELL LOCATION
(622.56)	GROUNDWATER ELEVATION
←	GROUNDWATER FLOW DIRECTION
620.00	GROUNDWATER CONTOUR

NOTES:

1. STATIC WATER LEVELS MEASURED 3/8/95
2. THE WATER LEVEL AT DB-1 MAY BE INFLUENCED BY LOCAL SUPPLY WELLS

<940387-2> 40387H04 8/28/95
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LAIDLAW WASTE SYSTEMS

15550 68TH AVENUE
COOPERSVILLE, MICHIGAN 49404

940387

FIGURE 13

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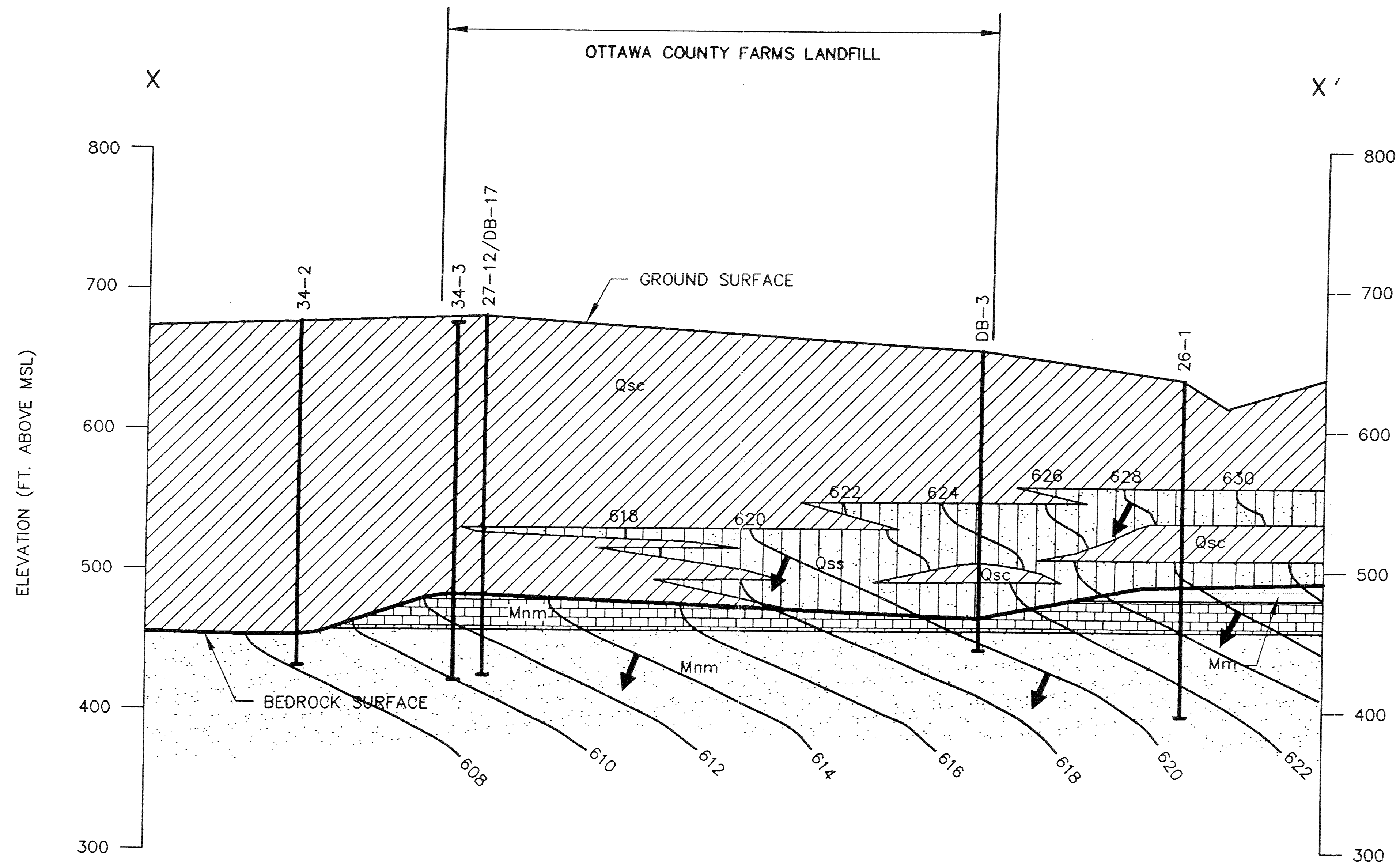
QUALITATIVE FLOW NET



SCALE
HORIZONTAL : 1"=1000'
VERTICAL : 1"=100'

LEGEND

Qsc CLAY

Qss SILT, SAND & GRAVEL

Mm MICHIGAN FORMATION; GYPSUM & SHALE

Mnm MARSHALL FORMATION; LIMESTONE & SANDSTONE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

NOTE:
SEE FIGURE 6 FOR LOCATION OF CROSS SECTION

<940387-5> 40387H17 10/11/94
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LAIDLAW WASTE SYSTEMS 15550 68TH AVENUE COOPERSVILLE, MICHIGAN	940387 FIGURE 16
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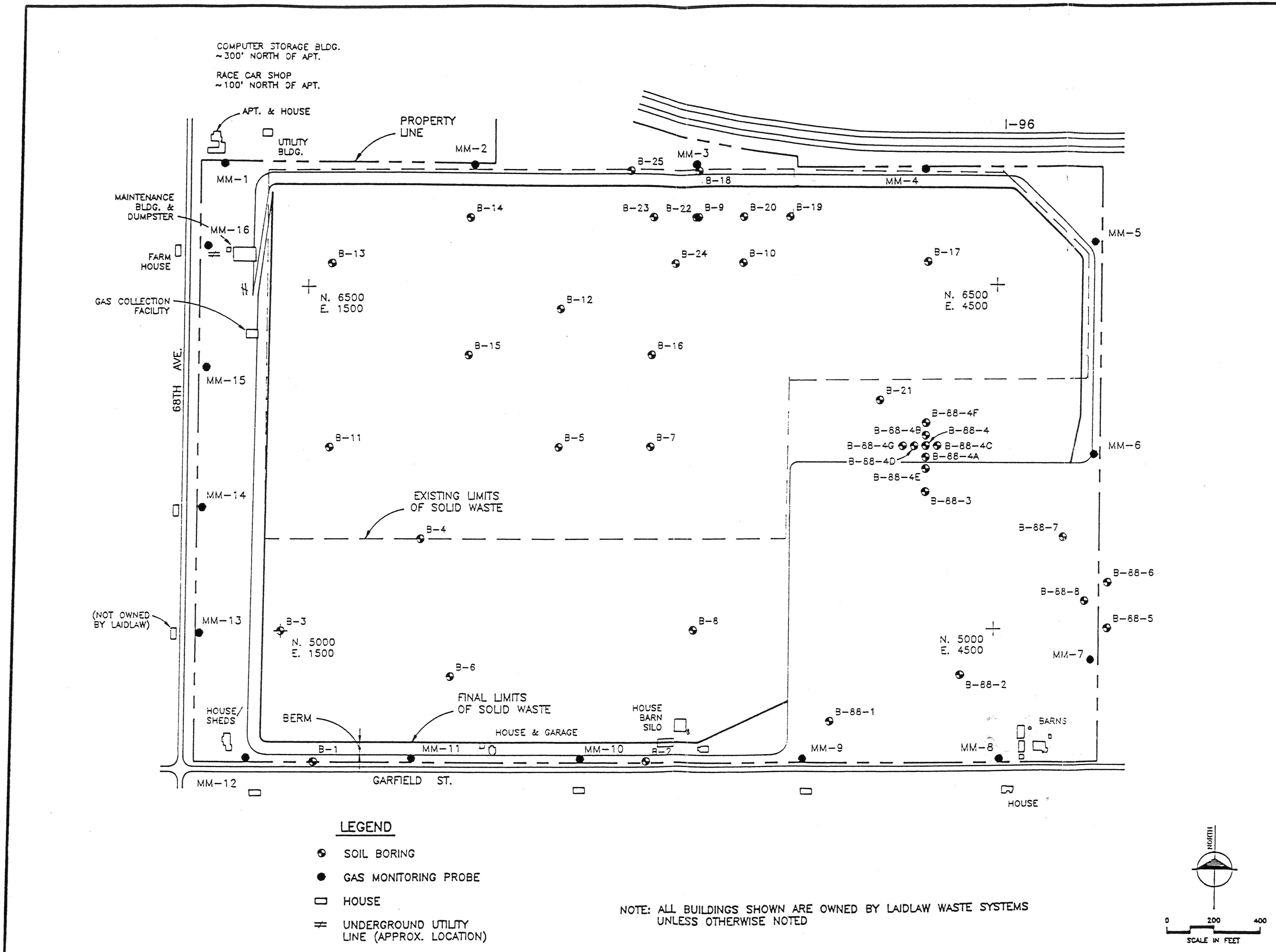

PROJECT

Laidlaw Waste Systems, Inc.

Ottawa Co. Farms Gas Monitoring Plan

TITLE

Site Map Outline

DRAWN BY	MAP
DESIGNED BY	MAN
CHECKED BY	
DATE	SEPT. '93
FILE	06181SMO
EDIT	MAP100693
SCALE	1"=400' DRAWING 1:400 PLOT
REVISE	
PROJECT	06181

FIGURE 2.1.2

SHEET NO.